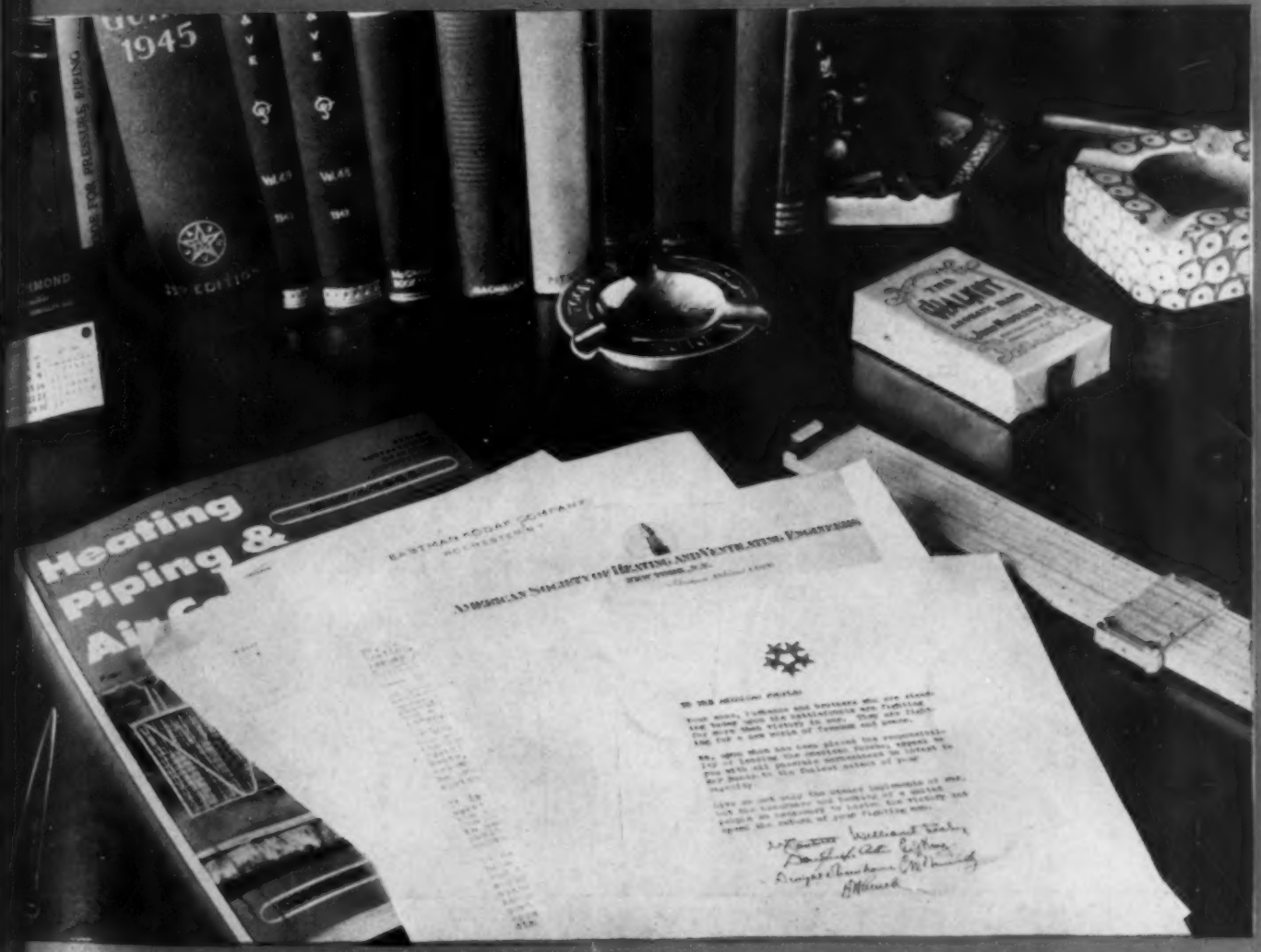
Heating Piping & Air Conditioning

DESIGN
INSTALLATION
OPERATION
MAINTENANCE

JUNE ★ 1945

INDUSTRIAL
COMMERCIAL
INSTITUTIONAL AND
PUBLIC BUILDINGS

331 — Journal Section of the American Society of Heating and Ventilating Engineers



HERE'S AN important "five-star" letter for you, and all Americans!
—see page 63.

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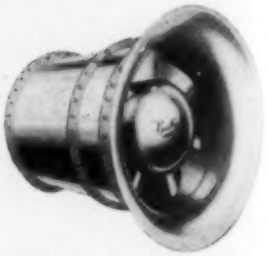
CLEARING THE DUCTS FOR ACTION

When one of our new super-battleships like the 45,000 ton Iowa throws its "Sunday punch" at the enemy, it must have plenty of air. Even when riding quietly at anchor, fresh air in unfailing supply is the breath of life to fighting men and machinery alike, everywhere in its vast interior.

To keep ventilating ducts "breathing" efficiently in the heat of battle, the Navy had to be *tough* in its specifications for every last detail of their design and construction. Star's assignment was building motors to turn the fans. As it has done so often before, Star was able to meet or exceed the specifications for these motors, and deliver *on time!*

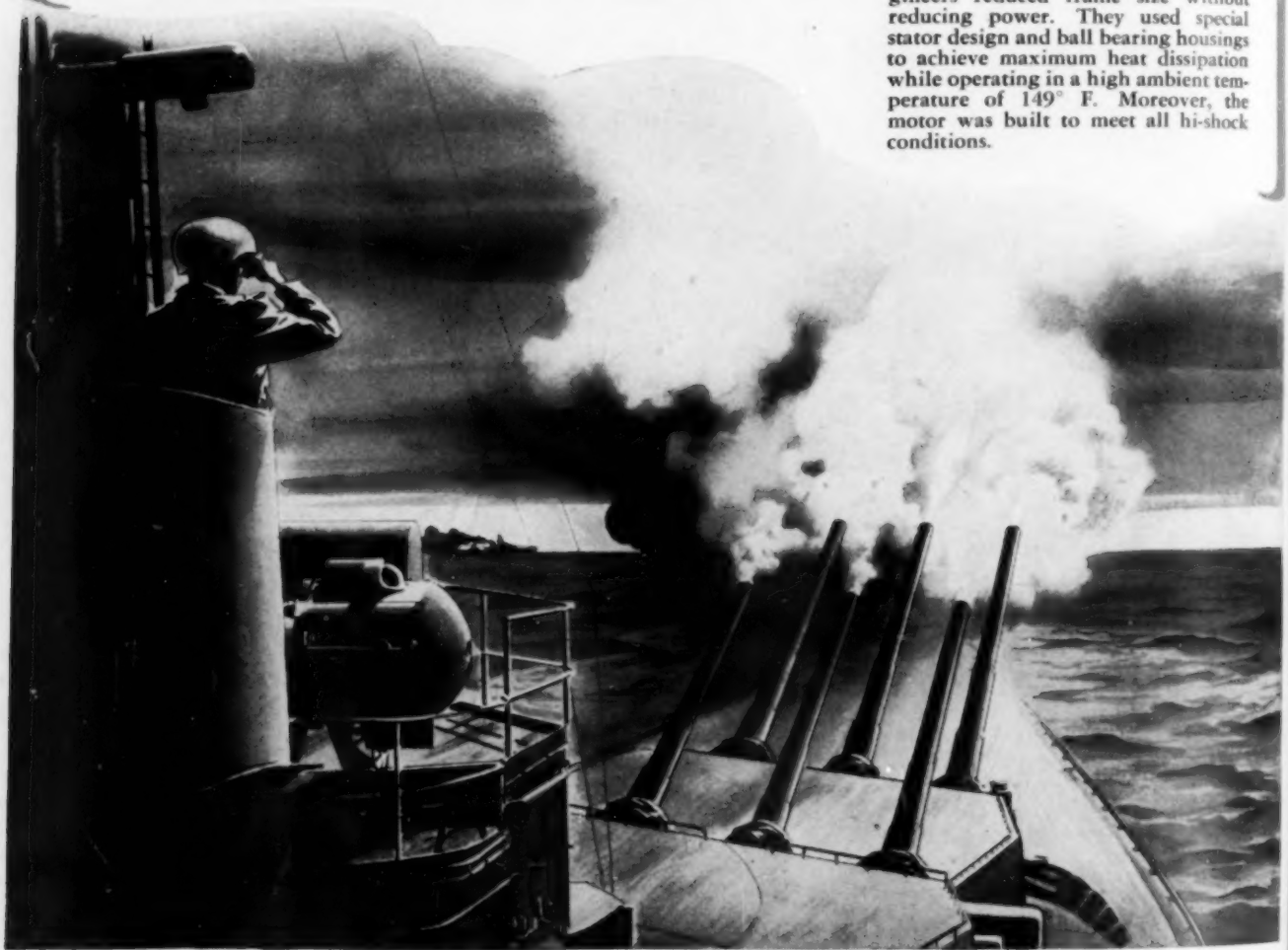
What Star has done on this and other jobs for the U. S. Navy . . . the World's Toughest Customer . . . it can do for you. While the Navy never endorses any product, the fact that Star has long been a Navy supplier should tell you what you want to know about Star Motor performance. If a standard Star Motor (⅛ to 200 H.P.) does not meet your requirements, tell us your special needs, and we'll build one that does! Star Electric Motor Company, Bloomfield, N. J.



Satisfying the World's Toughest Customer

This axial flow ventilating fan, used on all six of the new 45,000 ton *Iowa*-class, and on four of the 35,000 ton *North Carolina*-class battleships, is made by Buffalo Forge Company.

Engineering a motor to power this fan typifies the tough Navy problems Star has solved so many times. Since the fan had to be installed directly in the ventilating duct, an exceedingly compact motor was a "must". Star engineers reduced frame size without reducing power. They used special stator design and ball bearing housings to achieve maximum heat dissipation while operating in a high ambient temperature of 149° F. Moreover, the motor was built to meet all hi-shock conditions.



STAR MOTORS

POWER PACKAGED AS YOU NEED IT

CONTRACTORS HOLD "CONVENTION IN PRINT"

The Heating, Piping and Air Conditioning Contractors National Association, its 56th annual meeting (which was to have been held in Cincinnati) called off because of wartime restrictions on travel, is presenting a "convention by mail" through the pages of the HPA-CCNA Official Bulletin. The May issue gives the reports of the various officers and committees on the year's work, and the following number is planned to include discussion of the reports, the membership being invited to take an active part in the discussion.

The "convention in print" opens very suitably by presenting the officers and directors, followed by greetings from the national president, Daniel Hayes. Secretary Joseph C. Fitts then gives his report, in which he asks the cooperation of the members in HPACCNA statistical surveys on labor, overhead, purchasing power, etc.

In the report of the committee on air conditioning, A. C. Buensod, chairman, emphasizes the importance of maintenance and servicing of existing equipment, as it is felt there will be a considerable lapse of time before new equipment will be available to replace the older systems now operating. This committee feels that a plan which would enable offering a complete maintenance and repair service to users of air conditioning should be developed; suitably protected by appropriate insurance, it would cover repair parts due to wear and tear, and breakdowns due to faulty equipment, his report states.

William V. Hoier, chairman, reports for the committee on apprenticeship, and stresses—in referring to several requests from refrigeration companies that their apprentices be trained specifically in their specialties—that the industry's needs must be taught completely to its apprentices and specialization in any one part of the curriculum should not be encouraged or tolerated by the committee nor recommended to the schools which teach the trade.

In a brief report for the committee on certification, Chairman Thomas C. Douglass cites the certified heating program as a protection against "a breakdown in the quality of heating jobs . . . as occurred during the 1920's." The committee is studying the advisability of revamping the certified heating insignia to improve its eye appeal, and will welcome suggestions.

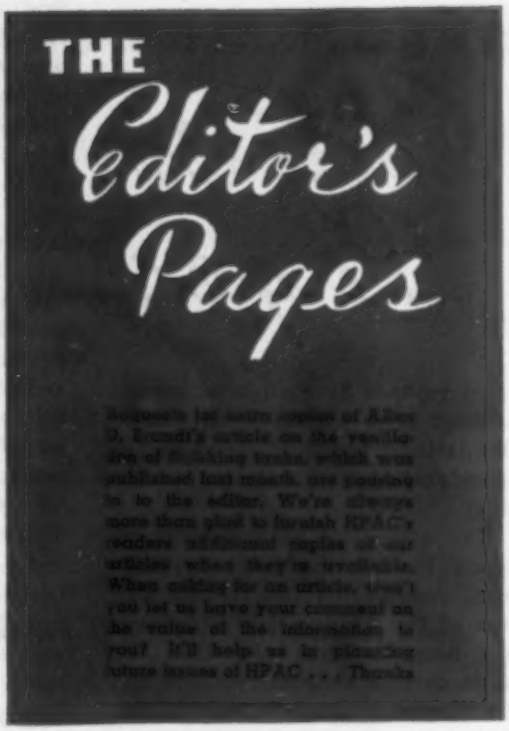
Panel Heating

J. A. Ljunggren reports for the home heating committee, and says that there seems to be a trend toward the use of panel heating—floor, ceiling, and wall radiant heating. If such installations can be embodied under the certified heating program, the industry will have made one of its greatest strides in years, he feels. A growing demand for individual heating systems in multiple unit apartment buildings, by using heater closets in each apartment, is also mentioned in his report. There is an extensive need for small heating units suitable for this type of installation, he says, "each of which should be a complete package consisting of a gas burning heat exchanger, fitted with circulator, relief valve, gages, with controls attached and wired." Ratings as low as 30,000 Btu output should be included, he feels.

William J. Olvany, general chairman of the membership committee, recommends in his report the formula "Ask Them to Join," and says that since the last convention 56 prospects to membership have been elected. J. M. Anderson reports briefly, for the publication committee, on advertising in the Official Bulletin.

George H. Dickerson, representative on the board of the Plumbing and Heating Industries Bureau, states that the purpose of bureau publicity is "prospect conditioning." Such publicity is important for two reasons, he believes. First, there is a public interest "greater than ever before" in building. Second, although there is a tremendous backlog of savings, there is an equally large backlog of wants and desires. Publicity is a factor in giving priority in the mind of the buyer to one or another contemplated purchase.

Robert B. Miller, reporting for the committee on industrial relations, says that a suggested standard form of local agreement which



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HERE'S A LETTER FOR YOU!

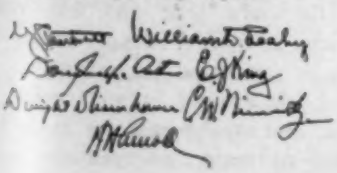
Here's the letter shown on our front cover. It's addressed to you, and to all Americans; it's from our five-star generals and admirals:

TO THE AMERICAN PEOPLE:

Your sons, husbands and brothers who are standing today upon the battlefronts are fighting for more than victory in war. They are fighting for a new world of freedom and peace.

We, upon whom has been placed the responsibility of leading the American forces, appeal to you with all possible earnestness to invest in War Bonds to the fullest extent of your capacity.

Give us not only the needed implements of war, but the assurance and backing of a united people so necessary to hasten the victory and speed the return of your fighting men.



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THE Editor's Pages

could be used by such local groups as need help, will be submitted to the national board of directors for consideration and appropriate action.

The committee on standards, of which Paul A. Edwards is chairman, reports that the fourth edition of the Engineering Standards has been finished, and that the parts on pipe sizes and design, and drafting room symbols and identification of piping systems, have been mailed to members. A bulletin on radiant panel heating is being prepared. The following additions to the standards would be of interest, he says: temperature control, both pneumatic and electric, with piping and wiring diagrams; ventilation, with method of figuring duct sizes, friction, metal gages, etc.; process piping, including water heating, with piping details for economizers, instantaneous and storage heaters; and pipe fabrication, expansion joints and bends, anchors, etc.

Shop Layout

Wray M. Scott, chairman of the committee on trade promotion, recommends in his report that the "best shops contest" program inaugurated this year should be continued as it might be possible to develop a certified shop program similar to the certified heating and certified welding programs. No company in the business can afford to be without a good shop, says Mr. Scott, regardless of its size. If the association's members will copy the better shops in the country, thereby improving their own efficiency, it will reduce their overhead expense as applied to the volume of work performed, he states.

The major activity of the committee on welding has been the completion of the 24 official qualification tests of the revised National Standard Welding Procedures and the printing and issuing of the procedures and records of the tests through the National Certified Pipe Welding Bureau, writes E. P. Everhard, committee chairman. As outlined at the Cleveland convention, the committee has continued to press for recognition by the codes of the principle of joint qualification of procedures and operators. A new development this year has been the "growing interest in chrome-molybdenum alloy as an inhibitor in pipe for steam temperatures above 900 F," and will be used in several installations later this year, he concludes.

John H. Zink, reporting for the editorial committee for the Standard Manual on Pipe Welding, estimates that preparation of the material for the book is 70 per cent finished, although "it is always difficult to estimate progress in editorial work by percentages." It is hoped that the complete project can be presented before the 1946 convention.

Pipe Welding

Roy M. Getschow, chairman of the board of trustees of the National Certified Pipe Welding Bureau, says that the bureau has been very active since the last HPACCNA convention and that standard procedures for metallic arc and oxy-acetylene welding of wrought iron, steel, carbon-molybdenum steel pipe, fittings, and flanges have been brought up to date and revised. These procedures are based on extensive experience of the HPACCNA's members. Under the procedures, says Mr. Getschow, it is only necessary for the individual member of a local welding chapter to qualify operators, who can then be interchanged between all members of the local welding chapter, thereby avoiding duplication of costs for the industry.

H. M. Hart reports for the boiler output committee an increasing interest and use of the Net Load Recommendations for Heating Boilers. As a war measure only, the committee has published net load recommendations for cast iron boilers in longer assemblies and requiring longer grates and higher combustion rates than it would recommend under normal conditions. The committee would welcome some discussion on the practical limit of grate length for hand firing, as there seems to be considerable difference of opinion on this. Mr. Hart calls attention to the fact that in the selection of heating boilers, the net load recommendations are minimum requirements, both as to boiler and chimney sizes, and that net loads should be calculated strictly in accordance with the instructions given in the foreword of the published data. Hot water requirements should not be neglected, and excessive heat loss from uninsulated or excessive piping should be carefully considered, he states.

Future of A.C.

The "convention by mail" closes appropriately with a note on the future. An association member has suggested that the future of air conditioning, and the place of the installing contractor in "this rapidly developing part" of the industry, be a subject for discussion. The HPACCNA invites written comment on this topic.

[The headquarters office of the Heating, Piping and Air Conditioning Contractors National Association is at 1250 Sixth Ave., New York 20, N. Y.]

SAVE PAPER TO HELP BEAT A JAP

Somewhere there's a homefront Jap who is pitted personally against you in this war. And you can bet that Jap is saving critical materials for all he's worth. Especially paper . . . because paper is today the very stuff of war. It makes or wraps over 700,000 items our armed forces are using right now to blast their way to Tokyo. The Pacific war is calling for vast quantities of paper packaging to protect vital supplies against the long sea journey, heat, cold, moisture, contamination and storage hazards. So won't you do this . . .?

Share this magazine with others.

Be sure that the last reader turns it in for salvage, unless it is to be preserved for reference.

Look around in your cellar, attic, and storerooms for those bundles of magazines you don't need any more . . . and turn them in!

Heating Piping & Air Conditioning

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Design, Installation, Operation, and Maintenance: Industrial, Commercial, Institutional, and Public Buildings

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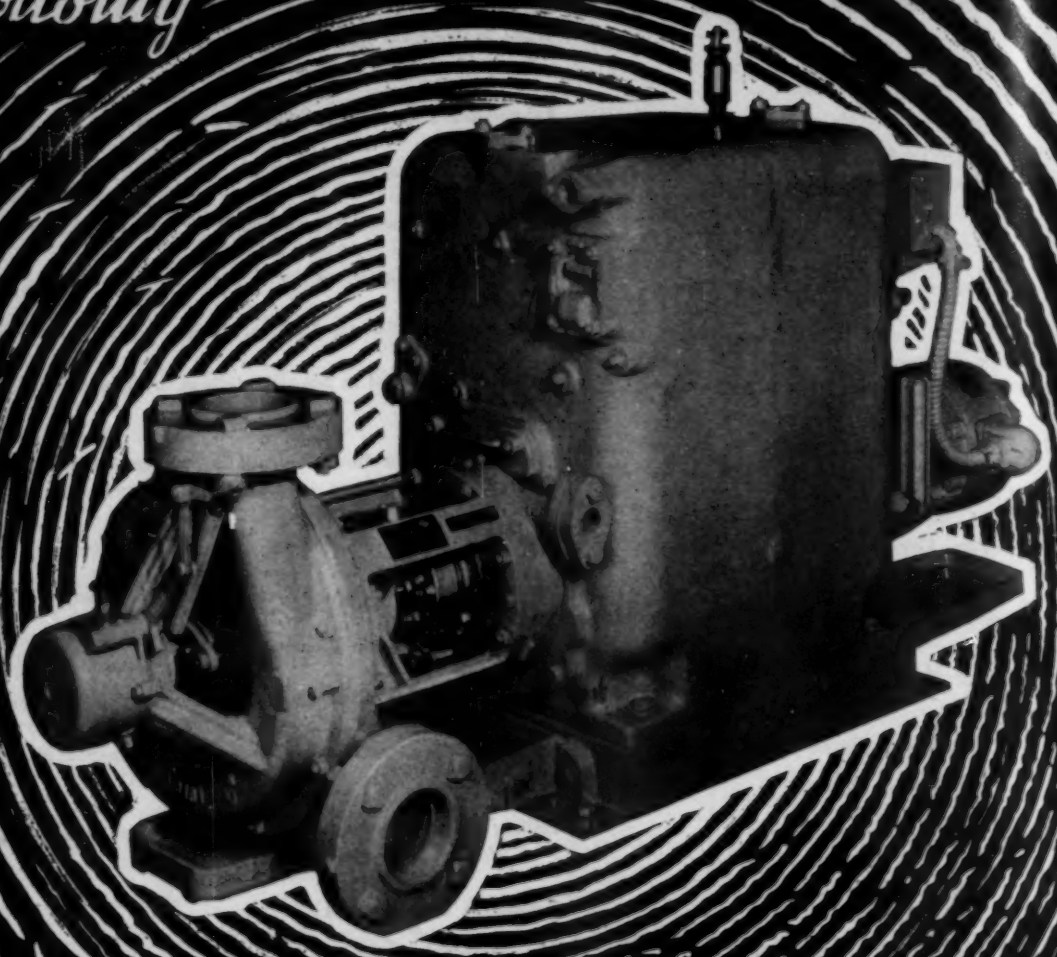
Centralized Heating Economy



A RETURN LINE VACUUM PUMP THAT CUTS HEATING COST.

This unusual pump needs no electric current, cutting out greatest item of pump operating expense.

More important, this pump insures absolutely uniform circulation in system. That means continuous steam economy.

Simple, compact, one moving element, no wearing parts, no internal lubrication. Bulletin No. 203 gives the facts. Your copy is waiting.

THE NASH ENGINEERING COMPANY
SOUTH NORWALK, CONNECTICUT, U. S. A.

When Is Complete Air Conditioning of the Modern Factory Advisable?

By H. A. Mosher, Mechanical Engineer
Kodak Park Works, Eastman Kodak Co.

ONE TREND which has been brought sharply into focus by the nation's rapidly expanded wartime production program is that of providing air conditioning in a wide variety of factory buildings. Numerous examples have been reported in Heating, Piping & Air Conditioning and other magazines. In considering such a trend, this question naturally arises: What are the conditions under which complete air conditioning of newly constructed factory buildings is justified? It is the purpose of this article to present some data to aid in answering it.

In most cases, the alternate to complete air conditioning of the factory space is to provide at least some measure of ventilation. Accordingly, in considering the desirability of complete air conditioning, the comparison should be made between results obtained with complete air conditioning and some predetermined standard of ventilation system. In a recent paper,* it was suggested that such comparisons be made with an "ideally designed ventilation system," which is capable of providing comfort to 75 per cent of moderately active workers for about half the summer working hours. This condition is comparable with that obtained in the past on ventilation systems designed by rule-of-thumb methods and before the current trend toward higher internal heat loads, particularly lighting. Those interested in judging the validity of the above assumed resulting conditions inside spaces using "ideally designed ventilation

*Air Conditioning vs. Ventilation Systems, by H. A. Mosher, Refrigerating Engineering, March 1945.

COMPARING COMPLETE air conditioning of a factory with an alternate "ideally designed ventilation system", the analysis given here shows that air conditioning is justified in many cases on the basis of saving in first cost alone. In drawing the comparison, it is assumed that the ventilation system should provide comfortable conditions for 75 per cent of the workers for about half of the time, which is not felt to be an unduly severe requirement. . . . In addition, of course, to the first cost there are many other factors which must be considered in deciding if complete air conditioning of an industrial plant is justified, and these are fully discussed by Mr. Mosher. He gives data not obtainable elsewhere in this important and interesting article on a subject which is becoming of increasing timeliness every day. . . . Don't fail to invest the time for a thorough and careful study of this material.

Table 1—Comparative results obtained in factory spaces using complete air conditioning, and ventilation systems.

Factor	With Complete Air Conditioning	With an Ideally Designed Ventilation System
1. Comfort index	71 F effective temperature year round will provide conditions comfortable to over 90% of the workers during all working hours.	An ideally designed ventilation system will provide comfort to about 75% of the workers for less than 50% of the summer daytime working hours.
2. Room air DB temperature	Can be held within ± 1 F.	Varies through range of approximately 75 to 100 F
3. Moisture content of air (in terms of RH)	Can be held within ± 5% RH.	Varies through range of at least 15 to 75% RH
4. Cleanliness of air supply	Up to 98% on smoke arrestance basis, without affecting resulting DB temperature or RH in space	Can be made comparable in arrestance with that of air conditioning, if building is completely closed and air from outside taken only from central filtered supply. In many cases this results in intolerably hot conditions inside the space

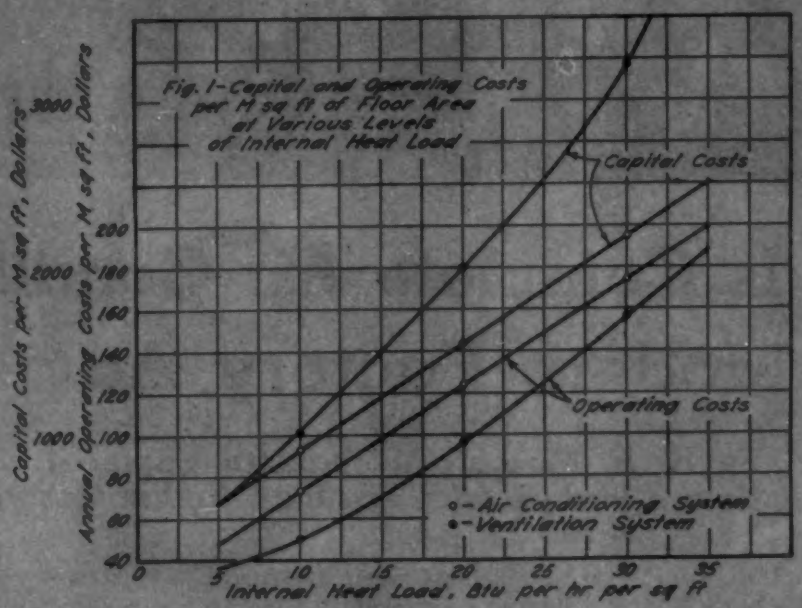


Table 2—Showing a summary of design factors from which cost data in Fig. 1 are derived[1]

	$H_1 = 10$		$H_1 = 20$		$H_1 = 30$	
	Air Cond.	Vent.	Air Cond.	Vent.	Air Cond.	Vent.
1. Cooling load, Btu/hr						
Conduction	78,100	—36,000	78,100	—34,200	78,100	—31,500
Sun effect	56,300	56,300	56,300	56,300	56,300	56,300
Internal	280,000	280,000	560,000	560,000	840,000	840,000
Subtotal	414,400	300,300	694,400	582,100	974,400	864,800
Outdoor air (net)	235,000	0	393,000	0	555,000	0
Total	649,400	300,300	1,087,400	582,100	1,529,400	864,800
2. Air volumes, total cfm	19,100	46,700	32,000	93,400	45,000	150,000
(a) cfm per M sq ft	680	1,670	1,140	3,330	1,610	5,360
(b) cost per cfm	$0.90	$0.60	$0.90	$0.60	$0.80	$0.60
(c) cost per M sq ft	$610	$1,000	$1,030	$2,000	$1,450	$3,220
3. Refrigeration, gross tons	54.0		90.5		127.4	
(a) tons per M sq ft[2]	1.6		2.6		3.7	
(b) cost per ton	$195		$195		$195	
(c) cost per M sq ft	$310		$510		$730	
4. Total capital costs per M sq ft	$920	$1,000	$1,540	$3,000	$2,180	$3,220
5. Annual operating costs[3]						
(a) Total	$2,035	$1,413	$3,469	$3,692	$4,881	$4,350
(b) per M sq ft	$73	$51	$124	$96	$174	$157
6. Resulting room conditions						
Max.[4] Dry bulb temperature	80.0 F	99.0 F	80.0 F	97.7 F	80.0 F	98.3 F
Effective temperature	72.5 F	86.9 F	72.5 F	86.5 F	72.5 F	86.3 F
Aver.[5] Dry bulb temperature	75.0 F	78.9 F	75.0 F	79.5 F	75.0 F	79.1 F
Effective temperature	69.2 F	72.5 F	69.2 F	72.5 F	69.2 F	72.5 F

[1]Based on one floor of a general purpose building having a floor area of 28,000 sq ft in Rochester, N. Y. In warmer latitudes, the comparison would be more favorable to air conditioning.
[2]At 82% diversity factor.
[3]Not including cost of heating building shell, which will be the same for either system.
[4]At maximum outside air conditions of 93°— 79°— 73.5°— 54%, in Rochester, N. Y.
[5]At average outside air conditions of 74°— 63°— 54.5°— 59% in Rochester, N. Y.

systems," and determination of the air volumes required to maintain such conditions, may refer to the treatment in the appendix to the present article, which will be published next month.

With the above as background, Table 1 has been prepared to show a qualitative comparison of the effect on several important factors when using, first, complete air conditioning and, second, the ideally designed ventilation system.

In considering the first of the factors shown in Table 1—comfort—the question naturally arises as to the relative cost between the air conditioning and the ideally designed ventilating system. For a building which does not have an unusually high ratio of exposed area to volume, it has been observed that the relative costs of either the ventilation or air conditioning system in a given space is almost entirely dependent on the level of internal heat gain in the space. Accordingly, Fig. 1 has been prepared to show both capital and operating costs for each type of system as a function of internal heat gain, H_1, in Btu per hr per sq ft of floor area.

In interpreting Fig. 1 it should be borne in mind that the ventilation air volumes have been based on providing a compromise comfort condition acceptable to only 75 per cent of the workers for something less than half the summer daytime working hours. The air conditioning system, on the other hand, will provide comfortable conditions for over 90 per cent of the people all the time.

It will be observed from Fig. 1 that air conditioning is less expensive than ventilation systems, in first cost, for all levels of internal heat gains above $H_1 = 5$. However, the operating costs of the air conditioning system are higher for all levels of internal loading.

At an average internal heat gain of $H_1 = 20$, the extra first cost of the ventilation system per M sq ft of floor area is $460. The additional operating cost for the air conditioning system is only $28 per year, which would not return the extra capital cost in less than 16.5 years. The additional investment in the ventilation system is, therefore, not justified, especially considering the extra advantages in greater comfort for more people for longer periods with the air conditioning system.

Table 2 shows a summary of basic data from which the cost information in Fig. 1 was derived. These figures are taken from the actual calculations of a proposed general purpose building having a floor area of 28,000 sq ft per floor. The operating costs were based on the cost of purchased power for a large user in Rochester, N. Y., and although these might vary between localities, it is not believed that the conclusions would be materially affected. Note also that all costs have been based on outside summer weather conditions for Rochester. In warmer latitudes, the comparison would be more favorable to air conditioning.

Many modern production jobs require air conditioning

Economic Justification of Air Conditioning

With certain exceptions which will be noted later, it may be concluded from the foregoing cost analysis that in areas having internal heat gains greater than $H_1 = 5$, air conditioning systems are justified over ventilation systems on economic grounds alone, without regard to any other advantage which might obtain with the former type of system, such as improved control and quality of product, or increased worker efficiency. This may seem to be an unusual conclusion and may be questioned by some. The reasons for this conclusion are as follows:

1) The increased level of lighting load in modern factories in recent years (in spite of improvements in the efficiency of lighting application, such as the increased lumens per watt when using fluorescent lighting) has resulted in a much greater increase in air volumes required for ventilation than for air conditioning. Since the first cost of both types of systems is almost proportional to the volumes of air circulated, this results in a marked advantage to the air conditioning system.

2) The continual improvement in air diffusion devices in the past 10 years has permitted introducing conditioned air into spaces at considerably lower temperatures and without objectionable drafts. This makes it possible to care for a given heat load in a space with lower volumes of conditioned air than those previously used. No such reduction applies, of course, in the case of ventilation air volumes.

The exceptions under which the foregoing cost analysis does not apply are as follows:

1) When good natural ventilation is obtainable—this will be the case in large open areas, without partitions, without external obstructions, and with windows exposed to provide cross ventilation with prevailing winds, or in areas having high ceilings, with sidewalls or roofs vented to take advantage of stack effect. In these cases, the large air volumes naturally circulated through a space provide in effect the required effective temperatures at no capital cost. This is not desirable, however, in areas where a high degree of cleanliness is required for production reasons.

2) In areas where the level of internally generated heat is unusually low (less than $H_1 = 5$) in which little or no ventilation would ordinarily be installed.

3) Special processes requiring

Table 3—Showing comparative unit change in dimension, due to a temperature variation, when using ventilation and air conditioning systems

Material	Approximate Maximum Unit Change in Dimension Due to Temperature Variation, in Inches per Inch of Length	
	With Air Conditioning	With Ventilation
Glass, plate or crown	0.00001	0.0001
Steel	0.00002	0.0002
Brass	0.00003	0.0003
Plastic—laminated—thermosetting phenolics	0.00003	0.0003
Plastic—wood filled—thermosetting phenolics	0.00007	0.0007
Hard rubber	0.0001	0.001
Cellulose nitrate (motion picture film)	0.0002	0.0020

outside air volumes greater than 20 per cent of the conditioned air volume, or where the quantity of conditioned air is determined by factors other than heat gain, such as in processes where it is necessary to exhaust large air quantities.

Even in cases where these exceptions apply, however, it may still be desirable to install complete air conditioning, in order to make effective the advantages for air conditioning shown for the remaining three factors in Table 1.

Quality of the Product Manufactured

It will be observed that these three latter factors are concerned with the quality of product which can be manufactured. For example, a nationally known mechanical engineering consultant has been quoted as follows: "It is known to be impractical, for instance, to build high powered airplane engines without control of moisture and dust in the air." In fact, the list of manufacturing operations which are affected to a more or less degree by one or more of these last three factors in Table 1 is continually expanding and it therefore seems desirable to examine each of them in more detail with the object of determining—if possible—the range of manufacturing (or operating) conditions in each case which will require air conditioning.

Room Air Dry Bulb Temperature

Room air dry bulb temperature is, of course, primarily of importance as it affects the degree of physical expansion or contraction of the manufactured parts. If ventilation is to be satisfactory for a given operation, the design tolerance must permit expansion or contraction of a given part through the temperature range stated in Table 1, or about 25 F. As an aid in judging the importance of this effect, Table 3, showing the maximum change in dimension of a given part per unit of length, over the range of temperature variations encountered with both ventilation and air conditioning systems, is given for various types of materials of manufacture.

The data in Table 3 should be interpreted with great care. For example, the maximum unit change in dimension, in ventilated spaces, of the two metals shown approaches the range of accuracy which is possible for various machining operations in many machine shops. However, many parts may be designed so that dimensional changes of the order shown may be tolerated. Furthermore, the micrometer gages used in making such measurements will usually be undergoing similar dimensional changes to those of the manufactured part, so that the importance of temperature variation would be minimized, except in applications using material having unusual expansion properties, or where complete interchangeability of parts made at widely different times is essential. Thus, dry bulb temperature regulation to prevent dimensional variation would probably not ordinarily be justified for conventional machine shops unless precision of the order of 0.0001 in. or less tolerances were common and possible.

At the other end of the scale in Table 3, however, consider a material having unusual properties of expansion in a process requiring, for example, slitting and perforating cellulose nitrate film to tolerances of, say, 0.001 in. Here, the best possible control of dry bulb room air temperature is certainly required, since—from Table 3—the variation in dimension of a film 1 in. wide, when using ventilation, would be greater than the allowable tolerance.

To summarize the second factor in Table 1, then, regulation of the dry bulb temperature alone will not ordinarily justify installation of air conditioning in those locations where exceptional conditions do not permit justification solely on the basis of economic considerations. In certain cases, however, where extreme precision is required and is possible, or where materials of manufacture having high temperature coefficients of expansion are used, dimensional change with wide temperature variation may become a factor, and these cases should, of course, be judged individually upon their own merits.

Table 4—Favorable conditions of temperature and relative humidity for various manufacturing processes

Industry & Product	Process	Temperature, F	Relative Humidity, Per Cent
Textile—Cotton	Carding	68-73	50
	Combing, spinning, spooling, twisting, and warping	68-73	60-65
	Weaving	68-73	75-80
Textile—Wool	Carding	73-77	65-70
	Spinning, storage	73-77	55-60
	Weaving	68-73	50-55
Textile—Silk	Dressing, weaving, spinning, and throwing	70-77	60-70
Confectionery	Chocolate enrobing	65	< 55
	Hard candy	70	< 50
	Storage	30	< 70
		59	< 55
Tobacco	Softening	84	85
	Cigar and cigarette making	70-73	55-70
Printing	Lithographing, binding	70	45
	Relief and offset	77	45
	Folding	77	65
Baking	Dough fermentation	81	65
	Proofing	90-95	80-90
	Loaf cooling	70	65
Electrical cable	Winding insulation	< 104	< 5
Cellulose lacquers	Application	75	< 20
Munitions	Fuse loading	70	55
Food—Cereal	Prepared, crisp cereals	73	45-50
Photographic—papers	Storage, cutting, and packing	75	42

Moisture Content of Air

Moisture content of air is of great importance in a wide variety of manufacturing operations. Hygroscopic materials (including foodstuffs, textiles, papers, leather, lumber, numerous plastics and chemicals, and many others) all are subject to important variations in such physical properties as weight and density, dimensional stability, pliability, strength, and the like. The variety of these materials involved and the consequence of inadequate moisture control is so diversified that analysis on any generalized basis is impractical. For convenience, however, Table 4 is partially reproduced from the International Critical Tables, Vol. II, showing recommended conditions of relative humidity for various manufacturing processes.

Another limited field in which the control of the humidity in spaces has resulted in improved quality of product has been a reduction of markings on highly polished surfaces due to perspiration on the hands of workers. On metal parts, this effect has been claimed to result in "etching" of the fingerprint pattern into the part, and on such optical parts as lenses or reticles, for example, it has resulted in obvious impairment of optical quality. Regulation of the room air humidity so as to provide effective temperatures for optimum comfort of the workers prevents the perspiration, with consequent improvement in the quality of the product.

Summarizing again, concerning the third factor from Table 1, air conditioning will be justified over ventilation systems, regardless of economic considerations, in processes where the materials of manufacture undergo intolerable changes in physical properties, due to their hygroscopic nature, as a result of variation in relative humidity of room air through a range from 15 to 75 per cent. Also, improvement in quality of the product will be obtained with air conditioning in processes where perspiration from the hands of workers has been shown to have a harmful effect on the product.

Cleanliness of the Air Supply

Cleanliness of the air supply, the fourth factor from Table 1, is not ordinarily of sufficient importance in itself to justify the specification of complete air conditioning in areas where the stated exceptions do not permit its justification on economic grounds alone. This is because the same degree of cleanliness in the space can be secured by providing proper filtering facilities on either type of system—ventilation or complete air conditioning—and the cost of providing this facility has been included in the unit cost for each type of system.

However, a requirement for extreme cleanliness in the working space can preclude the possibility of caring for internally generated heat loads by natural ventilation means, since air to such spaces must be supplied from a central filtered source, and the building kept closed as much as possible to prevent infiltration of dirt laden air. Thus the cleanliness factor can change the status of a given application from one to which the first of the exceptions previously noted might apply, to one which can be analyzed on economic considerations alone, and hence air conditioning may be justified over the ventilation system.

The importance of the cleanliness phase makes it worthwhile to discuss some of the problems connected with providing as nearly as possible a truly dust free atmosphere in the working space. It is, of course, recognized that proper filtering of supply and maintenance of slight pressures within the space to insure against infiltration of unfiltered air is of importance. It is also true that control of dirt generated internally within the space, from such sources as wear on floor and shoes, flakes of dead skin and dandruff, lint from clothing, and many everyday activities causing abrasion and consequent breakdown in size of materials, is of at least equal importance in critical processes.

Table 5—Dirt and lint propagation in critical assembly area. (Particles per sq ft per hr)

Position of Dish	Lint	Brass	Iron	Metal from Grinding Wheel	Miscellaneous**
In air stream	1				
On air outlet, leaving room	11	1	2		2
On stockroom wall, above work level	96	3,130	1,490	43	43
Near south elevator	39	77	43	60	426
Above work level (south end)	120	*	*		1,940
Above work level (north end)	13	*	*		90
On work bench, center of benches	205	1,490	170		426
Below work level (south end)	115	*	*		2,560
On south elevator	85	*	*		8,520
On north elevator	398	*	*		13,800

*Indicates particles included under miscellaneous.
**Miscellaneous particles include soot, wood, sand, cement, skin, hair, brick, metal, and grease.

To illustrate the importance of such internally generated dirt, Table 5 has been prepared from data which were obtained in a critical manufacturing area in which every care had been taken to exclude foreign particles from the outside and in which the finest filters had been installed in the supply air.

The data in Table 5 were secured by exposing a shallow cellulose acetate dish, coated with a tacky Canada balsam-xylene solution, to the atmosphere in the space at various locations and levels for a known period of time. The dishes were then examined microscopically and the particles counted, and reported as the number of particles settling on a square foot of horizontal surface per hour.

From the data in Table 5, the following conclusions can be drawn:

1) Air supplied from the filter system was clean.

2) Some contamination entered the room from the elevator shafts; the shafts contained large amounts of foreign material.

3) Most of the foreign material present in the air was generated within the room.

4) Very little of the dirt present was removed in the air leaving the room; most of it settled back into the space.

On this particular project, the re-

quired level of cleanliness in the space was obtained only after providing extensive equipment for carrying out this critical assembly operation inside protective enclosures on each work bench, which were each supplied directly from the filtered air source. Other experience in areas requiring extreme cleanliness has proved that dirt generated internally is of prime importance, requiring care and ingenuity in its control, at least equal to that required in control of foreign particles in the supply air.

Worker Efficiency and Cleaning Costs

There are, of course, factors other than those listed in Table 1 which affect the decision to install air conditioning in factory buildings. Two of the more important of these—improvement in worker efficiency, and reduction in cleaning costs—are not discussed extensively in this paper because of their controversial nature. It is the opinion of the writer that, while there are many applications where installation of air conditioning will result in improved worker efficiency, there are likewise many others in which no such improvement occurs. Broadly speaking, it is believed that such improvement can be expected on jobs where the resulting output of product is proportional to the degree of physical effort, but that little or no improvement can be expected on jobs where the output is machine paced, or where the physical effort required is at a constant and relatively low level. Certainly, considerable more experimental data are required before this factor can be claimed as one favoring installation of air conditioning in all cases.

Regarding the other factor, reduced cleaning costs, it would seem that, as in the discussion of the fourth factor in Table 1, it must be conceded that an equal reduction in cleaning costs may be expected with either air conditioning or ventilation systems by providing equal cleaning facilities in both types of equipment. Thus, as before, the only advantage in this connection would result from reclassifying a given project from one to which the previous economic analysis would not apply to one which could be so treated, and hence air conditioning justified on the basis of lower first cost alone.

HERE'S SUMMARY OF THIS ARTICLE

To summarize the overall comparison given in this article, the following conclusions for new factory construction are in order:

1) In spaces having an internal heat gain higher than 5.0 Btu per hr per sq ft of floor area, in which outdoor air requirements for exhaust or other purposes do not exceed 20 per cent of the conditioned air volume, and where good natural ventilation is not obtainable, the capital cost of air conditioning is less than that for a high standard of ventilation system. Yearly operating costs for such air conditioning systems are higher than those for the ventilation systems for all levels of internal loads, but the savings are not sufficient to make the extra first cost of the latter systems an economically sound expenditure. At average internal loads of 20 Btu per hr per sq ft of floor area, the savings in operating cost of the ventilation system will represent a return on the extra investment of only about 6 per cent.

2) The ventilation system on which the above cost comparison is based will provide comfort to about 75 per cent of the occupants for less than 50 per cent of summer daytime working hours in Rochester, N. Y.; an air-conditioning system would be comfortable to over 90 per cent of the workers all the time.

3) For processes which cannot thus justify air conditioning on a purely economic basis, the improvement in quality of product by regulation of dry bulb temperature alone will not ordinarily provide such justification. In locations where extreme precision is required (instrument shops, master gage control rooms, and the like), or where materials of manufacture have a high temperature coefficient of expansion, this factor may be of sufficient importance to indicate the choice of air conditioning.

4) A wide variety of processes, involving the use of hygroscopic materials, will not tolerate the physical changes in the material which result from the wide variations in relative humidity common to ventilation systems. Also, a limited field of processes are adversely affected by the markings on polished surfaces resulting from perspiration on workers' hands. In all these cases, air conditioning is required irrespective of the economic considerations involved.

5) Many modern production jobs require a high degree of cleanliness of air in the working space. Proper filtering of supply air is only a partial answer to this problem, since foreign particles generated internally within the space are equally detrimental. However, both these phases may be cared for with equal effectiveness when using either an air conditioning or a ventilation system. The precautions necessary to provide the proper degree of cleanliness may, however, preclude the possibility of satisfactorily treating a given space by natural ventilation, and thus result in a cost analysis favorable to air conditioning.

6) The available data regarding other factors affecting the choice of air conditioning, such as improved worker efficiency, are inconclusive, although there are undoubtedly conditions under which such improved worker efficiency will obtain, and will thus recommend the choice of complete air conditioning.

7) In no important respect is the air conditioning system believed to be inferior to ventilation systems.

Rehabilitating the Public Utilities of Paris

By J. T. Whitney, Lt. Col.,
Corps of Engineers, U. S. Army

IT IS DIFFICULT to picture a more complicated engineering job than that represented by the rehabilitation of the electrical, gas, water, sewer, transportation, and other public utility services of a large city following its liberation from the enemy's forces. Colonel Whitney, writing from Paris, describes in some detail here the various steps in getting the utilities there back to something like "normal." It is a story that all engineers, no matter what their particular lines of endeavor, will find of extreme interest. The great importance of the available fuel supplies is shown.

Paris, May 15

THE REHABILITATION of the public utilities of Paris began immediately following the departure of the Germans. Because of their hurried exit, the Germans had little if any time to damage utilities. The principal damage to the electric system was to the transformers at the Chevilly station, the terminus of the 90 kv and 220 kv lines from the south, and was caused by bombing prior to the liberation of Paris. The French Maquis had also blown up a section of the underground 220 kv cable.

The principal damage to the water supply system was to the filter beds, but this did not cause a serious handicap to operations. The outfall sewage pipes supported by one of the bridges of the Seine, located near Colombes, collapsed with the bridge when bombed, making necessary the pumping of sewage directly into the Seine at a different location. Bomb damage occurred also in the northern portion to one of the principal sewers, making necessary temporary diversion through an open ditch.

The Metro (subway) system was not in operation, the only use of the system being for air raid shelters at certain stations.

Garbage and refuse incineration offered no problem because the scarcity of food and other materials resulted in very small quantities.

Those utility companies and organizations formerly and still responsible for service began immediately the rehabilitation of the public utilities of Paris and also throughout the liberated portions of France. The U. S. Army helped much with technical advice, by loan of trucks and equipment, and in some cases by supplying material needed for repairs, gasoline, oil, and food. There was neither time nor material to rebuild steel transmission towers, so wood frames or poles were used. To supplement the scant coal supply, coal yards and coal bins were cleaned out, even though only two tons were available. At one of the stations formerly using pulverized coal, the boilers were converted, and captured road oil was burned to make possible an increase in the amount of electricity. After the gas works

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were started, the resulting gas oil was used when the supply of road oil became exhausted.

Close Cooperation of U. S. Forces and French

The reason for the rapid and highly successful accomplishment of restoration of services to the French utilities was the close cooperation of the U. S. forces and the French utility organizations, and the utilization of all means possible to secure results.

At the time the U. S. forces arrived in Paris, only three generating machines—one in each of three stations—were operating, producing about 1,100,000 kwhr per day. These machines were all steam driven turbines and were all that could be operated with the limited supply of coal available. A 90 kv line was hastily repaired to the hydro plant at Eguzon—about 190 miles south of Paris. Then a second 90 kv line was repaired to the same point. A line to Lille near the Belgian border, a distance of about 125 miles, was then repaired to make available the surplus electricity produced by thermal plants at the mines. Then followed the repairs to the two 220 kv lines from the Massif Central region, 315 miles, from which later a line was repaired extending westerly 190 miles from the Massif Central to hydro plants in the Alps. Lastly, a line was repaired from Paris running easterly, then southerly to the same hydro plants in the Alps 280 miles away, to act as insurance in case of the loss of one of the 220 kv lines to the south. (These lines went out of commission several times, due to the high winds and snow.)

While these repairs were taking place, the railroad lines to the north and south were being restored, the debris of bombed bridges being cleared out of the canals, and barges sunk in the canals were being floated. Again the French and U. S. engineers, working together, produced results. Coal for fuel gradually began to move into Paris, but the canals became unusable in December due to heavy rains which raised the water level, making passage of barges under the bridges impossible. When the water subsided sufficiently, the barges began to move, but due to lack of tugs, slow operation of locks, etc., the amount of coal was not as much as desired. In January, a period of very cold weather caused eight inches of ice to form in the locks and canals, which again stopped canal traffic. But in February the ice melted and traffic was again resumed, only to be stopped again by flood conditions. Every effort was made to conserve fuel by bringing

in the maximum amount of imported electricity. Far more electricity than was first contemplated was found to be possible from the hydro sources, due to the unusual amount of rain in October and November.

Electric power production reached a figure of 12,767,000 kwhr per day by the 31st of December 1944, having started with 1,100,000 kwhr on September 1. In September, at the start, 15 per cent of the 1938 load was being produced, and in December 105 per cent of the 1938 load for the corresponding period. The system peak had increased from 90,000 kw to 755,000, about 92 per cent of the 1938 peak.

Use of Electricity Rationed

In the beginning, strict control of the use of electricity had to be exercised. The civilian rationing established under German domination was continued, namely, each family being given an allotment for the month of 20 kwhr, plus 20 kwhr for each person in the family. All commercial and industrial customers were given fixed monthly allotments, with heavy penalties for over runs. Penalties imposed were 3 francs per kwhr for 30 per cent of the excess over the allotment and 6 francs per kwhr for the other 70 per cent. If excessive use continued, the electric service was discontinued until such time as the customer's quota caught up with the use. Military users cooperating with the electric authorities maintained close supervision over the consumption in military establishments.

For several months current was not available during the daytime, except for priority military and civilian installations and it was often necessary to use separate lines from such places to a high tension post which had continuous service. In December 1944 the city of Paris went on a 24 hr schedule, which had to be discontinued again between January 15 and February 19, 1945, when the coal supply on hand for electrical production dropped to 5000 tons—at a time when practically 5000 tons per day was being burned in the various plants. Since February 19, the service has continued on a 24 hr basis.

Fuel consumption of coal and oil during the first week of September was the equivalent of 980 tons of coal daily. For the last week in December 1944 (using coal only) the consumption was 4600 tons per day.

The thermal plants in Paris are used to maintain voltage and to augment the hydro power as the electric demand requires more electricity. There are five thermal plants built at different times—some have been modernized. Most of the boilers use pulverized coal, although in the emergency several have been converted to oil. Electric current is supplied to the electrified railways, to the Metro, and to the telephone system for recharging batteries. Most of Paris proper has direct current, but a program was developed several years ago for alternating current and several districts now have single or two phase current.

The 220 kv cables from the hydro system extend around the easterly part of Paris, from Chevilly station in the south to Villevaudé, thence through Clichy-sous-Bois to the thermal stations at St. Denis and Gennevilliers in the Paris suburbs on the north side. The last portion passes underground. These cables have a hollow core through which oil is pumped to prevent overheating. This arrangement has proved most successful.

Current is distributed at 60 kv within the city over two loops to substations on the high tension network, where it is transformed to

lower voltage for local distribution, and to substations on the outskirts of the city proper, when it is reduced in voltage and distributed in the suburbs by other companies.

The principal damage was to the Chevilly transformer station, where three of the four 60,000 kva transformers were badly damaged by bombs; to the 90,000 kva transformer at the Gennevilliers station which was not injured but which was tipped and had to be jacked back to a vertical position and underpinned. The resulting loss in transformer capacity was partially overcome by moving a 20,000 kva transformer from Chevilly to St. Denis and in conjunction with two 30,000 kva transformers at the latter station, made possible 65,000 to 70,000 kva additional capacity which increased the kwhr output by a million.

The normal transformer capacity was 540,000 kva, but the system is now operating with 340,000 kva capacity.

During the operation at the Gennevilliers station, one of the turbines overspeeded when the station attempted to carry the load during a sudden outage on the transmission lines. The safety controls failed to function in time and the turbine blew up, damaging five other turbines and wrecking the entire roof.

The chief operating difficulties were the overloading of circuits and the inability to meet these fluctuations due to the shortage of coal. To overcome this, the city had to be sectionalized and overload relays installed for each station. Two groups of relays were set to drop the load, the first group operating when the frequency dropped to 48 cycles and the second when the drop reached 47 cycles. The normal frequency is 50 cycles.

1700 Miles of Water Piping

Due to the extensive character of the water system, a large portion of normal service could be given although the system has suffered damage. Normally, the supply of *drinking water* brought into Paris by aqueducts amounted to about 117 million gallons per day and 140 million gallons per day from plants on the Seine and Marne rivers, totalling 257 million gallons. Only about 156 million gallons per day was available because of damage. The repairs made permitted the supply to rise to 173 million gallons per day, which represents about 67 per cent of the normal supply.

The water system for the city of Paris is entirely separated from the surrounding suburbs. It was constructed and is owned and operated by the city. The distribution of water, the billing, and collection of revenues from customers is delegated to the Compagnie Générale des Eaux.

Spring water is brought from collecting sources 40 to 80 miles from Paris by means of aqueducts, which average about 8 ft in diameter. Siphons are installed under the numerous streams. The water is chlorinated at the source and does not require filtration. These aqueducts, four in number, total

American troops march through Arc de Triomphe in a parade to celebrate the liberation of Paris (Signal Corps photo)

269 miles in length and have a daily output of 144 million U. S. gallons.

In addition to the aqueducts, two plants supply water for drinking, taken from the Marne River at St. Maur and from the Seine River at Ivry. From these plants the water is pumped to three large collection reservoirs where it is treated. The two plants have a total daily capacity of 145 million U. S. gallons. The capacity of the reservoirs totals 170 million U. S. gallons. Six smaller reservoirs are located at strategic points around the city to maintain adequate pressure in the distribution supply.

The distribution system has 1700 miles of piping ranging from 1½ in. to 43 in. in diameter. The hydrants and public utilities which require a continued pressure are connected to the drinking water system.

The principal damage to the water system was the cutting of one viaduct due to the destruction of the viaduct bridge. A temporary siphon was installed which reduced the daily capacity about 35 per cent. Severe damage to one of the filter units reduced the capacity at that plant about 40 per cent. Reconstruction is already in process.

The *raw water* normally used for industry, street cleaning, public gardens and fountains, and other places where pure water is not needed, is secured from the Ourcq canal, artesian wells and two old aqueducts, and formerly amounted to 200 million gallons per day. Owing to the lack of electrical energy, which was due to the lack of coal, strict limitations were imposed on the consumption of water and the pumping was kept between 30 and 50 per cent of normal. An average of 60 million gallons per day was pumped in September; increased requirements for industries raised the average to 90 in December.

Extensive Sewer System

Paris has one of the most extensive and well developed sewer systems of any of the world's large cities. It is a combined sanitary and surface drainage system designed to care for 400 million U. S. gallons per day.

Five large trunk mains, called

American infantry gather before the obelisk in Paris during a mass parade August 29, 1944, after occupation by Allied forces (Signal Corps photograph)

"collecteurs," gather the sewage from all parts of the city. All converge on the pumping plant at Clichy in the northwest part of Paris. These "collecteurs" are 16 to 18 ft in diameter. Smaller sized laterals feed into the main collectors and the laterals are in turn fed by the street mains.

At Clichy and Colombes are located the two largest pumping and treatment stations. At Clichy, the larger part of the solids is removed by primary and secondary sedimentation tanks, after which the effluent is pumped through the "Aqueduc d'Achères" to the Colombes station. At this station the effluent is pumped to a tank on high ground at Argenteuil from which it flows by gravity to sewage farms, 5 to 10 miles down the river. Four conduits, each one meter (3.281 ft) in diameter, carrying the effluent to Argenteuil, cross the Seine River on a specially constructed bridge. This bridge with conduits was wrecked at the liberation of Paris and it has been necessary since to discharge the effluent into the river. Three bad breaks in one of the main collectors have been repaired and repairs are now in progress on other damage. The sewage, in some cases, had to be diverted around the breaks and run in an open ditch.

The sewage will continue to be pumped to the Seine as a temporary expedient until the former damaged outlet sewer lines can be repaired, which, however, will take considerable time.

How Gas Service Was Restored

Just before Paris was liberated, the general distribution of gas ceased. Only enough fuel was available to maintain a minimum pressure in the gas mains. A survey of existing fuel stocks showed coke on hand enough to supply 25 days of operation on 1 hr of general gas distribution per day, *if* a supply of oil could be obtained for the manufacture of carburetted gas. Minimum requirements per day appeared to be 1,600,000 cubic meters of 3300 calories per cubic meter. On September 7, 1944, gas service was started for *1 hr* a day. In September, 30,471,000 cubic meters was produced. (One calorie equals 3.9683 Btu and one cubic meter is 35.315 cu ft.)

On October 9, 1944, general gas service was increased to 2 hr a day —1 hr at noon and 1 hr from 7 to 8 p.m. Beginning November 6, 1944, an additional half hour of gas service was given in the evening and the calorific value was increased to 3550 calories per cubic meter.

On December 4, 1944, the gas service was again increased from 2½ to 13 hr per day. The increased time was from 8:30 p.m. until 7:00 a.m. in order that the civilian bakeries could use gas during the night. (The bakeries had to work at night as electricity was more available. Electricity was not given to industry in the daytime, in order to save fuel. There was enough hydro power at night.)

There were 76,251,700 cubic meters (3550 calories per cubic meter) of gas produced during the month of December 1944. Production had risen from zero on September 1 to 88 per cent of the 1938 figure for December (based on a calorific value of 4500 calories per cubic meter), 1938 being considered the base year for nor-

nal comparison. During the four months, September to December inclusive, about 30,000 tons of the coke made from the coal consumed in the manufacture of gas was made available to other consumers.

Normally, the Paris region uses more than one-half of the total gas produced in France. All production is manufactured gas and over 50 per cent of the coal used was imported from Great Britain. About 16 per cent of the gas used in Paris is for industrial purposes, with the greatest part of the remainder used for domestic cooking, with some used for heating.

Production is primarily by coke oven type plants supplemented by water gas sets. The output of the three companies serving the Paris region is 2,183,000 cubic meters per day at normal times with a calorific value of 4500 calories per cubic meter.

Power Allotment for Subway System

The subway system of Paris, commonly called the Metro (Compagnie du Chemin de Fer Métropolitain de Paris), was not in operation when the American forces reached Paris. On September 11, 1944, eleven lines and a limited number of passenger stations were placed in operation between 6:00 a.m. and 10:00 p.m., with service restricted to 3 min intervals during rush hours and 6 min at other times. No service was authorized for Saturday afternoon or Sunday operations. To provide for this service, a daily allotment of 410,000 kwhr was made by the French director of electricity, this amount being about 41 per cent of the power required for normal operation.

In October, the power allotment was increased to 510,000 kwhr per day, which permitted, beginning October 7, the operation of service on Saturday afternoon and Sunday. On October 23, seven more passenger stations were placed in service.

A further increase in power allotment to 540,000 kwhr made possible, on October 30, the adding of two more lines to the operating schedule with four stations and on November 6 the service was extended daily to 11:45 p.m. On November 20, twelve more stations were opened to the public with an increase of power allowed to 580,000 kwhr, and on December 4 another increase to 610,000 kwhr made possible the opening of eight more stations.

The year 1944 closed with all lines in operation on a limited stop and time schedule except for one line. This particular line had to be reserviced as the Germans had removed the rails and concreted over the right of way for use as underground shops. The concrete has been removed and on March 5 this line with its stations was reopened to the public. On the same day, about 15 additional stations were opened, the escalators being put in operation for those stations where the subway is the greatest distance below the street level. The electric power requirement jumped to 760,000 kwhr per day. On April 1, the power allotment was increased to 850,000 kwhr per day, which is about 85 per cent of normal.

The next step in the program of transportation will be to increase the number of trains, especially during rush hours on the busiest lines. In a short time, probably about 1,000,000 kwhr will be required for the Metro operation.

This system is one of the most heavily travelled railroads in the world. There are 15 lines, 750 kilometers of track,* and 230 stations on the system. In December 1944, the system was carrying about four million paying passengers and about 150,000 military (carried free) per week. The system is owned by the city but is operated by the Compagnie du Chemin de Fer Métropolitain.

The power supply for the system is a 10,500 volt alternating current network, with the current converted to direct current at 21 substations spaced about 3 to 5 km apart around the system.

*A kilometer is approximately 0.62 miles.

Program Depended on Close Supervision of Fuel

Although fuel is not usually considered as a public utility, the consumption and distribution so vitally affected the electric, gas, and water utilities that it was necessary to maintain close supervision from the beginning. At the time of liberation, fuel stocks were practically exhausted. The chaotic condition of the railroad and canal systems due to bombing blocked all normal channels for the movement of coal to Paris. Available trucks could not be used as they were necessary for handling food supplies. Over half of the locomotives and rolling stock had been taken by the Germans. The remaining equipment was considerably damaged. However, by utilizing available equipment after such repairs as were possible had been made, together with hasty repairs to the railroad tracks to the north, it was possible to make a start on moving coal into Paris. In September 1944, 9000 tons a week were received and the amount grew to about 75,000 tons a week by April 1945.

Barge deliveries via the canals and the Seine river were blocked by sunken barges and the destruction of locks and bridges. Strenuous efforts by the army and French authorities resulted in the rapid clearing of the canals. About the middle of November 1944, coal by barges began to arrive in Paris at the rate of about 1900 tons a week, gradually increasing until 22,000 tons per week were delivered in April 1945.

Lack of pit props, lack of transportation facilities, high water resulting from floods, making impossible the passage of barges under bridges, and freezing weather causing ice up to 8 in. in thickness in the locks and canals all contributed to the difficulty of moving fuel.

"Open for Discussion"

CHANGING OR CONSTANT TEMPERATURE?

THE EDITOR—I rise to applaud the discussion by F. C. McIntosh in the April HPAC (pages 193-194) on the subject, Changing or Constant Temperature? It seems about time that all of us who have to deal with true air conditioning recognize the shortcomings of oldfashioned heating techniques.

Certain weaknesses in heating systems are brought forcibly to our attention when the customer permits the occupants of the space to express a real opinion as to whether they like it or not. The idea that if you had too much heat it was the occupant's problem has just about lived its life, and we are now faced with the responsibility of applying automatic heating that will be suitable for the average person.

Panel Heating and Cooling Effects

Due to the panel cooling effect or, as Mr. McIntosh says, the irradiating effect of the body toward a cold surface, we find it is absolutely essential to have a warmer temperature in cold weather than in mild weather. This is particularly true if you have offices with window exposure or glass block exposure. Single windows with steel sash are the worst offenders, then comes glass block, and then double windows. Unless you can eliminate the panel cooling effect of a cold outside wall you have to raise the temperature as the outside temperature falls to zero.

Entirely independent of that change is the change due to a reduction in humidity, as the comfort chart very plainly shows the difference in effective temperature as humidity drops. Therefore, the winter heating control must be something which senses panel heating or cooling effect and humidity and relates that measurement back to the apparatus.

As a corollary to the panel cooling effect is the panel heating effect, which comes with warm ceilings due to excessive light loads. Sometimes the panel heating of the ceilings is fighting the panel heating of a big radiator, which in turn is fighting the panel cooling of a large glass area. There is a need for some rational thinking when it comes to designing heating systems that will be suitable for our present day, well-lit, and large glass area offices.

Shock Effect Isn't Controlling Factor

The original thinking that the cooling required a differential due to shock has been changed, as it isn't the shock effect which is the controlling point, but rather the panel heating effect of hot walls. You will find that for good summer air conditioning, temperatures will have to vary from 72 deg to 81 deg as the outside varies from 60 deg to 105 deg, due more to the effect of hot panel walls and ceilings than because of the change in the shock effect. This sounds like a paradox, and that is that in the summertime you should raise the temperature inside the conditioned space to counteract panel heating, whereas in the wintertime you raise the temperature to counteract panel cooling. The point seems to be that if you try to hold any such thing as a 72 deg temperature against hot walls and ceilings the incoming air supply is so cold that you create extremely bad draft conditions. It is only by letting the inside temperature rise that you balance out on a compromise between room temperature, supply air temperature, and the surrounding wall temperatures. Here again the question of humidity is important so that the higher inside temperatures can only be successfully used with low humidities, say 40 per cent.

The summer cooling load is complicated by the panel heating effect of warm floors over unconditioned areas, panel heating of ceilings under dead air space or directly against the roof, and the panel heating effect of light added to the roof load. Then you have panel heating of sun on the glass block or window glass. If window glass is protected inside with venetian blinds or window shades you have converted all—or practically all—of the radiant heat to panel heat inside your room. Some of these problems a control man can solve with new and better equipment, but essentially the problem is one of design, and the best approach is to make the building more suitable for air conditioning by using proper materials and arrangement.

Better Building Design

If we leave this entirely to the control man he should provide us with room control sensitive to effective temperature plus radiant heat effect and air motion effect, which controller could be set slightly upward in the wintertime and slightly upward in the summertime. Sounds complicated to me!

Possibly we could persuade the architect to design a building suitable for human occupancy, thus simplifying the thermostat requirements.—LESTER T. AVERY, president, Avery Engineering Co.

ISOMETRIC PIPING DRAWINGS

THE EDITOR—Thank you for calling to my attention the two articles by V. L. Sherman on perspectives and isometrics in the engineering drawing field, which articles were recently published in HPAC. I read them with much interest because I am personally acquainted with Mr. Sherman and his interest in the subject—as well as being directly connected with drawing—and am interested in learning of new ideas and approaches to the subject.

Usually I do not argue too much about terminology. If Mr. Sherman wishes to call "isometrics" by the term perspective I will not complain as long as he is clear in his discussion as to what he means. The word perspective to me means a picture. If one stops here in his definition, "isometrics" could be

classed as perspective. However, my own preference would be to stick to the classification as given by Prof. Jorgensen in his discussion of Mr. Sherman's article printed on page 130 of the March HPAC. This classification is standard.

War Production Has Emphasized Pictorial Drawings

The true value of the articles comes in their suggestion that more use be made of the pictorial representation of objects (machine parts, piping, ventilating ducts, etc.). The war production effort has emphasized pictorial drawings for workers unskilled in reading multiview orothographic drawings. The writer, while in Portland, Ore., last summer visited the production illustration department of the Oregon Shipbuilding Co. Here they were using true perspective for piping and ductwork as well as for other applications. Three-point true perspective was made easy by special "perspective" boards with perspective scales etched on the board. Although the drawings were made to scale the final drawings could not be scaled in the shop.

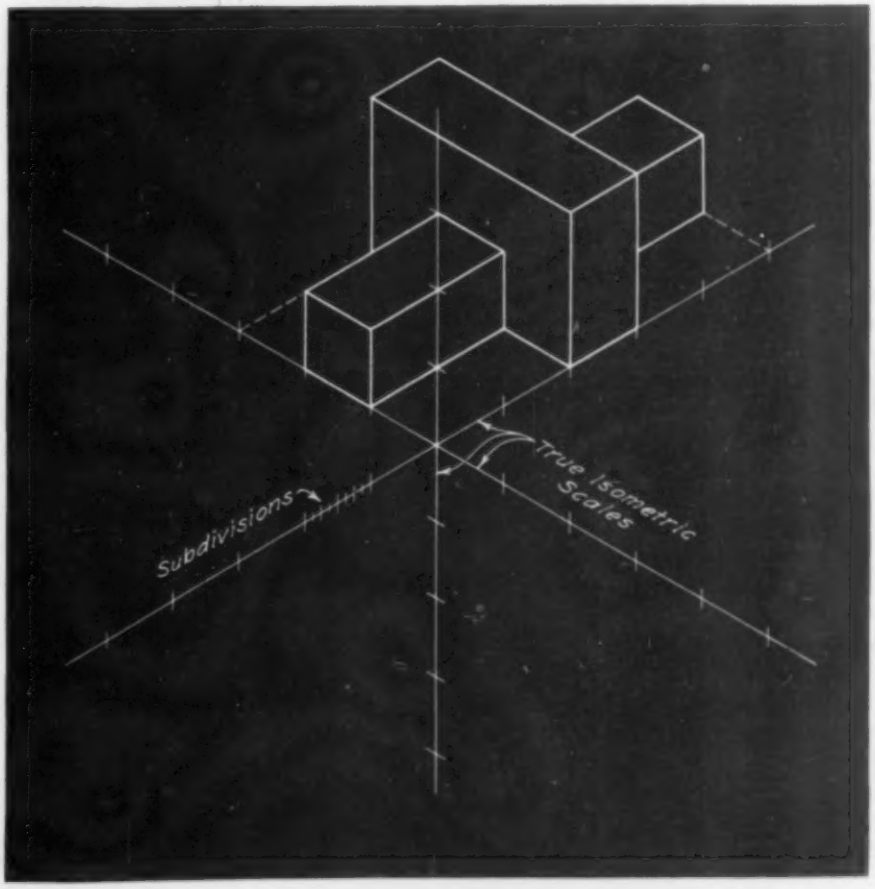
The type of pictorial drawing to be used depends upon the ease with which one can make the drawing and upon its purpose. Any aids that can be suggested to reduce the labor of making such pictorial drawings should be welcome. Mr. Sherman's suggestion of a grid system laid off according to true isometric projection makes for quick and accurate design sketches. Why not carry this one step further in a similar manner as the perspective boards are made as used at the Oregon shipyard and other places? On the board isometric lines could be drawn or etched intersecting at one point near the center. These lines could be marked according to Mr. Sherman's suggestion. The three isometric lines would now be the "isometric scales," per the accompanying sketch. This would permit readily drawing in true isometric projection, thus getting away from the disadvantages of the usual isometric drawing.

Having such a board and a 30-60 deg triangle, any draftsman could quickly make "perspectives" (using Mr. Sherman's terminology). Also, a set of the Lietz ellipse guides will reduce the amount of work required. At the present the writer feels that the greatest usefulness of "perspectives" lies in the development of designs and in supplying a picture representation for assembly purposes—also, for catalog cuts and such illustration. The working drawing is still best represented in orthographic multiview drawing.—H. LOREN THOMPSON, The Technologic Institute, Northwestern University.

CENTRAL REFRIGERATION FOR AIR CONDITIONING

THE EDITOR—I have read with great interest the comments of A. C. Buensod and R. W. Waterfill in the "Open for Discussion" columns of the April HPAC on the subject of central station refrigeration for air conditioning. They referred to a comparison, which I prepared from the best information available at the time, of the horsepower requirements of two 7000 ton air conditioning systems in blackout aircraft factories (see HPAC, January 1944). One of these systems was of the central station type with steam turbine drive, and the other was of the decentralized unitary type using electric motor drive. This comparison showed the auxiliary power requirements of the central station plant to be very high as compared with the decentralized system.

Since the decentralized plant used electrical power and the central station plant largely steam power, it is regrettable that sufficient data were not available to convert the power requirements to a cost per ton basis. I agree perfectly with Messrs. Buensod and Waterfill that the comparison would be much better if converted to some common power basis, but believe the comparison will usually favor the decentralized unitary job. Unless the cost of power is abnormally high, I am firmly convinced that the central station steam job will always be at a disadvantage when put on the economic scales to balance against a decentralized unitary job (see HPAC, "Open for Discussion," September 1943).



Isometric lines could be drawn or etched on the board, which would permit drawing in isometric projection

WHEN ENGINEERS gather to hear a paper or talk, there comes a time when the meeting is thrown "open for discussion." We follow this custom in these columns, which provide an opportunity for readers to comment and discuss articles published in HPAC and other topics of interest to heating, piping, and air conditioning engineers and contractors. The editors will welcome your remarks. Address Heating, Piping & Air Conditioning, 6 N. Michigan Ave., Chicago 2, Illinois.

I agree that central station refrigeration jobs have their field, but where the cooling coils or cooling units are widely scattered, the conditions must be abnormal before the central job with its costly distribution system can be made to appear more economical than the unitary system. The trend of the times is toward standardized unitary equipment which can be manufactured cheaply by volume production methods. The trend of the times is also toward cheaper and more abundant electrical power.

This trend can be observed in the changing refrigeration methods over the past 10 or 15 years. Central station jobs using brine circulation used to be standard practice for market and apartment house refrigeration years ago. Now these systems are being torn out and replaced with small unitary apparatus. There is but little question that the unitary refrigerators have been more satisfactory from all angles than the central brine circulating jobs. The only restraining force from the beginning has been the economics of the situation, and this has been solved by volume production and the increasingly low power costs. As a result we have witnessed the phenomenal growth of the electrical refrigerator industry.

It is admitted that central chilled water distribution systems using centrifugal refrigeration may be installed in congested business or residential districts if their cost can be economically justified. With the trend of our industrial development so strongly toward low cost volume production of unitary apparatus, it is difficult to visualize any great number of such large district cooling systems.

In the end, economic considerations will govern regardless of the engineering refinements which are incorporated in the design of either type of system.—H. M. HENDRICKSON, assistant district chief engineer, York Corp.

TEMPERATURE CONTROL IN SCHOOL BUILDINGS

THE EDITOR—I've read Samuel R. Lewis' comments in the May HPAC on the desirability of room control thermostats in school buildings, and I agree of course, that besides savings of a third or more in the steam used for the year's heating, which pays the first cost out promptly, the improved comfort and efficiency of the space more than justifies the cost. As with other items of mechanical equipment, these very useful devices are sometimes not an unmixed blessing. In the fine warm days now at hand, the windows go up, and spring is admitted to the classroom. No mechanical devices have yet been invented to produce this grand effect. Cool air blows on the thermostats, and the windows are opened wider to admit more of the beautiful spring. Who cares then if a little more steam is used? —LYMAN R. FLOOK, superintendent, buildings and grounds, University of Chicago.

THE EDITOR—John Howatt's discussion in the May HPAC of schoolroom temperature control is timely, particularly with government rationing of coal for educational institutions to 80 per cent of their normal requirements.

The simpler installation involving a thermostat and one control valve on the steam supply main is more foolproof than the individual room thermostats, in my experience. The greatest difficulty with the single thermostat controlling a building is to locate it so that all or nearly all of the classrooms and laboratories are heated to temperatures that are acceptable to the occupants. The success or failure of such installation is largely determined by the temperament of the teaching personnel occupying the building. In some instances teachers are extremely sensitive to temperature variations. In many cases they insist on wearing clothes that are customarily worn in the summer months and expect to be comfortable in schoolrooms in the winter time. For these persons individual room control is indicated.

Where teachers are mechanically minded and tend to want to tinker with control apparatus we have found an educational program very helpful. When they are informed in the mechanics and the operation of the thermostats and valves, in many cases they are helpful in the operation of the mechanisms.

By and large, wherever the single valve and thermostat can be installed successfully in a school building or installed to control a zone in a school building, this mechanism will show the most satisfactory return on the investment. —LESTER S. RIES, superintendent, department of buildings and grounds, Oberlin College.

PRICES FILED ON MACHINERY REPAIRS

May 30 was the deadline for about 65,000 concerns and individuals engaged in jobbing shop operations performed in making metal products and repairing industrial machinery and ships to file their service prices, rates and rate-computing reports with the OPA, the agency has announced. Names of concerns whose statements have been received are being checked by OPA against master lists of jobbing shops performing industrial services throughout the country to determine those that failed to comply. Postcard reminders will be sent to firms that have not reported as required by maximum price regulation 581. Failure to receive a special notice, however, does not relieve a firm of full responsibility for filing.

Firms failing to comply may have their maximum prices fixed by OPA retroactively to March 31, 1945, when the new price regulation became effective.

All concerns should have filed with their OPA district office the prices, rates, and pricing methods they have been using.

Using the Velocity Head Concept in

PRESSURE DROP CALCULATIONS

By C. E. Lapple*

THE FRICTION loss or pressure drop through a bed of granular solids may be expressed as

$$F = \Delta p = (4f_2 L/D_p)\ (\rho V^2/2g_c) \quad \ldots\ldots\ldots [14]$$

$$\Delta p_v = (4f_2 L/D_p) \quad \ldots\ldots\ldots [15]$$

where f_2 is a form of friction factor which is a function of the Reynolds number, $(D_p V\rho/\mu)$, based on the particle diameter and the superficial fluid velocity based on the gross bed cross-sectional area.

Friction Loss Through Granular Beds

In Fig. 6 is given a plot of f_2 vs. Re taken from a correlation reported by Chilton and Colburn (Reference 30). This plot makes no allowance for particle shape or degree of packing, but represents an average value of f_2 for shapes and degrees of packing commonly encountered in practice. Actually the particle shape and degree of packing affect the value of f_2 as well as Reynolds number and for further data along these lines the reader is referred to References 28-32.

For an average value of 15.0 for f_2, which holds to better than ± 50 per cent for the turbulent flow range $(D_p V\rho/\mu > 80)$ and degree of packing commonly encountered in practice, Equation 15 becomes

$$\Delta p_v = 60\ (L/D_p) \quad \ldots\ldots\ldots [16]$$

which means that for each layer of particles (i.e. $L = D_p$), a pressure drop of 60 superficial velocity heads results. From a velocity head visualization and analysis, it would appear from this value that the maximum velocity head attained by the fluid in passing through a single layer of particles is on the order of 60 times the superficial velocity head. This would imply that the minimum cross-section available for flow between particles is on the order of 0.13 of the overall cross-section of the particle bed. The ratio of minimum flow cross-section to overall bed cross-section can be calculated as 0.09 and 0.21 for triangular and rectangular packing of uniform spheres, respectively. Thus, the pressure drop through each layer of particles may be visualized as on the order of one velocity head based on the minimum area available for flow between particles.

Friction Loss for Abrupt Expansion

The friction loss for an abrupt expansion as derived from a momentum balance is given by

$$F_v = (1 - a)^2 \quad \ldots\ldots\ldots [17]$$

where F_v is based on the velocity head in the smaller (upstream) cross-section and a is the ratio of upstream to downstream cross-section. Thus, for an abrupt expansion into a very large chamber $(a = 0)$, the friction loss is one velocity head.

The pressure drop for an abrupt expansion is obtained by adding algebraically the difference between the downstream velocity head and the upstream velocity head to the friction loss. The pressure drop for an infinite expansion is thus zero. For expansion into a finite area, the pressure drop is negative, which means that a pressure recovery is obtained.

DESIGN OF pipe lines, process equipment, ventilation systems, etc., requires estimation of pressure drops in order to specify the required pump, compressor, fan, or blower capacities. Pressure drop estimates are often necessary, too, in the operation of equipment for purposes of locating possible plugged or corroded lines, checking process performance, or determining bottlenecks for proposed capacity increases. The article of which this is the third and last part (the first was published in the April issue) is intended as a guide to a physical conception or visualization of otherwise seemingly complex fluid flow phenomena. The approximations presented will be found to be entirely adequate for many purposes, and an attempt has been made to point out their limits of accuracy.

Friction Loss for Abrupt Inlet

The friction loss for an abrupt inlet is given by

$$F_v = K_1(K_2 - a) \quad \ldots\ldots\ldots [18]$$

where F_v is based on the velocity head in the smaller (downstream) cross-section, a is the ratio of downstream to upstream areas, and K_1 and K_2 are constants determined experimentally. The inlet loss is due largely to a contraction of the stream at the inlet with subsequent partial recovery. The values K_1 and K_2 are found experimentally to be

For $a < 0.715$, $K_1 = 0.4$ and $K_2 = 1.25$
For $a > 0.715$, $K_1 = 0.75$ and $K_2 = 1.00$

The friction loss for an abrupt inlet from a relatively large chamber is thus found to be 0.5 velocity head based on the inlet area. The pressure drop is found by algebraically adding the difference between the downstream and upstream velocity heads to the friction loss. For an abrupt inlet from a large chamber, the pressure drop is thus 1.5 inlet velocity heads.

Differential Heads Across Metering Devices

For metering devices in which a differential head is measured, the flow rate is related to the differential head in terms of a discharge coefficient, C, defined in various arbitrary ways. It is also possible

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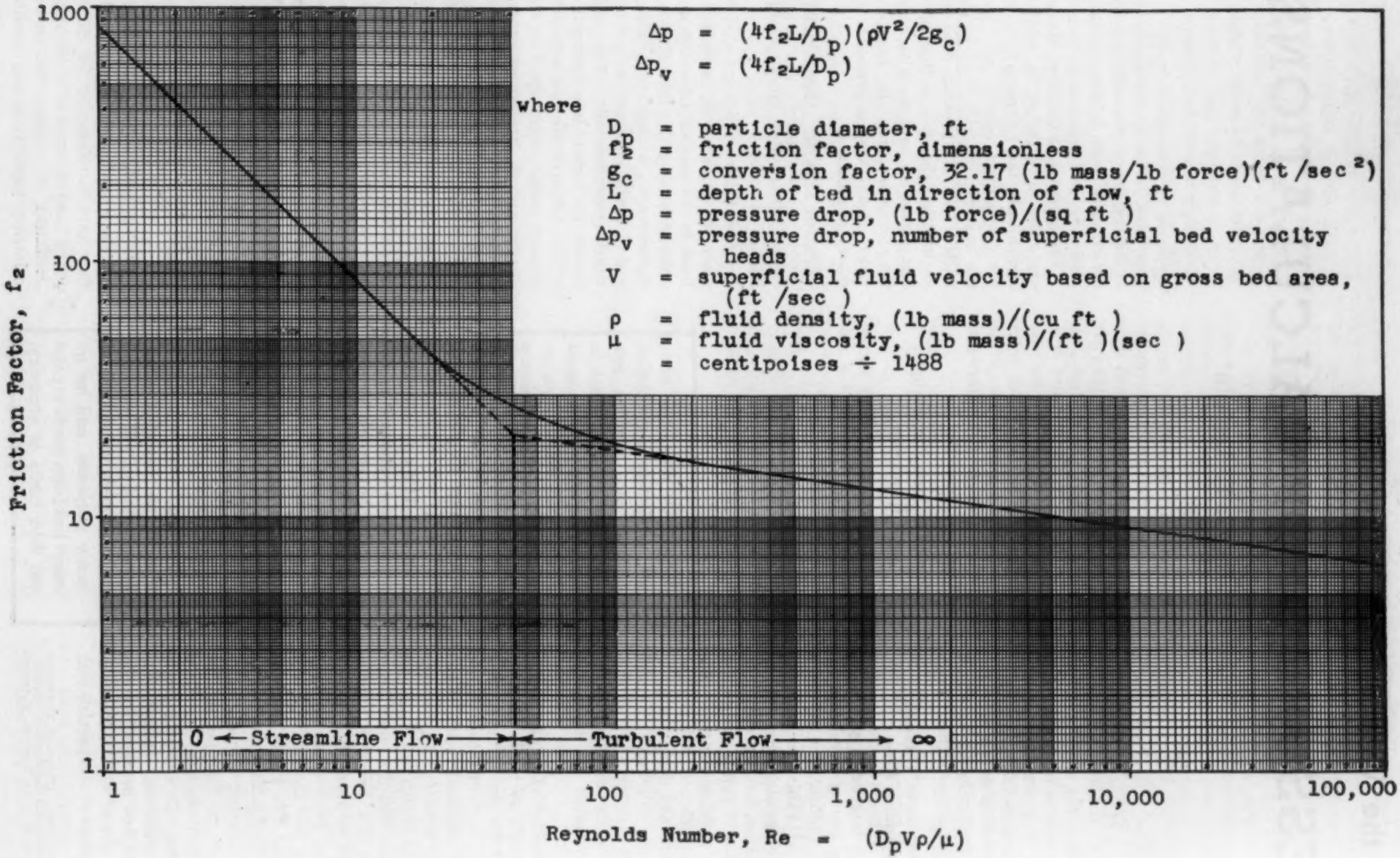
$\Delta p = (4f_2L/D_p)(\rho V^2/2g_c)$
$\Delta p_v = (4f_2L/D_p)$
where
D_p = particle diameter, ft
f_2 = friction factor, dimensionless
g_c = conversion factor, 32.17 (lb mass/lb force)(ft/sec^2)
L = depth of bed in direction of flow, ft
Δp = pressure drop, (lb force)/(sq ft)
Δp_v = pressure drop, number of superficial bed velocity heads
V = superficial fluid velocity based on gross bed area, (ft/sec)
ρ = fluid density, (lb mass)/(cu ft)
μ = fluid viscosity, (lb mass)/(ft)(sec)
= centipoises ÷ 1488
Friction Factor, f_2
1000
100
10
1
0 ← Streamline Flow → ← Turbulent Flow → ∞
1
10
100
1,000
10,000
100,000
Reynolds Number, Re = $(D_pV\rho/\mu)$

Fig. 6—Friction factor-Reynolds number plot for flow through beds of granular solids. (Average values for particle shapes and degree of packing commonly encountered.) (See Reference 30.)

to express the differential head in terms of number of velocity heads, as will be shown in the following examples for common metering devices.

Pitot Tube

The equation for calculating velocity from a pitot tube reading is commonly given as

$$V = C\sqrt{2g_c\,\Delta p/\rho} \quad \text{.....[19]}$$

where C is a coefficient depending on the type of pitot tube used and Δp is the differential reading obtained. This may be rewritten to express Δp as a number of velocity heads

$$\Delta p_v = \Delta p/(\rho V^2/2g_c) = 1/C^2 \quad \text{....[20]}$$

For the standard single-bend pitot tube, the impact tube records the static pressure of the fluid plus the impact or velocity head, while the static holes on the side record substantially the static pressure. The differential head is, therefore, substantially one velocity head, and C is experimentally found to be very close to unity. For a double long-bend pitot tube, the impact tube records the static plus impact pressure of the fluid, while the static tube records the static pressure minus a suction effect dependent on the kinetic energy of the fluid. The differential head is consequently greater than one velocity head by the magnitude of the suction effect. Experimental data indicate C for this type of tube to be 0.855 and hence Δp_v is 1.37, which means that the suction effect is equal to 0.37 velocity head. It should be pointed out that the velocity head in each case refers to that corresponding to the local velocity of the fluid stream at the point where the pitot tube is located.

Nozzle and Venturi Meters

For nozzle and venturi meters, the differential head, Δp, between an upstream pressure tap and the throat of the nozzle or venturi is related to the average fluid velocity at the throat by the expression

$$V = C\sqrt{2g_c(\Delta p/\rho)/(1-a^2)} \quad \text{[21]}$$

where a is the ratio of the throat to pipe area and C is a discharge coefficient. Written in terms of velocity head, Equation 21 becomes

$$\Delta p_v = \Delta p/(V^2/2g_c) = (1-a^2)/C^2 \quad \text{.....[22]}$$

where Δp_v represents the differential head in terms of velocity head based on the throat area. Expressing Δp_v as the differential head in terms of pipe velocity head, Equation 22 becomes

$$\Delta p_v = (1-a^2)/a^2C^2 \quad \text{.....[23]}$$

In this type of meter, pressure energy is converted into velocity energy in accelerating the fluid from the pipe velocity to the meter throat velocity and the differential head measures essentially the difference in velocity heads at the throat and in the pipe, plus any frictional losses encountered during the acceleration. The coefficient C is found experimentally to be 0.98-0.99 for Reynolds numbers, based on pipe velocity and diameter, greater than 10,000. Thus, Equation 22 indicates that the differential head is substantially one throat velocity head where the throat area is small compared to the pipe area. The differential head is greater than one throat velocity head by only 2 to 4 per cent due to frictional losses. For larger throat areas, the differential head is lower by one pipe or approach velocity head, which is allowed for in Equation 22 by the term $(1-a^2)$, which is commonly known as the velocity of approach correction.

Orifice Meters

For sharp-edged orifice meters Equations 21, 22, and 23 also apply, where V is the velocity based on the orifice area. The coefficient C, however, is found to vary with the ratio of orifice to pipe diameter, but for pipe Reynolds numbers greater than 10,000 and ratios of orifice to pipe diameter of less than 0.8, the value of C is substantially equal to 0.61 where vena contracta taps are employed.

A sharp-edged orifice differs from a nozzle in that the fluid stream contracts to an area less than that of the orifice due to the sharp edge of the orifice. Thus, the differential head from an upstream pressure tap to the vena contracta of the fluid stream must represent the difference in velocity heads at the vena contracta and in the pipe, plus any additional frictional losses. Since, in the usual equations, the velocity is based on the orifice area, the coefficient C must incorporate two factors, an allow-

Nomenclature

C = Discharge coefficient for orifice, nozzle, venturi, or pitot tube, dimensionless;
D = Inside diameter of circular pipe, ft;
D_c = Clearance between tubes in a tube bank, ft;
D_p = Diameter of granular particle, ft;
f_p = Friction factor for flow through beds of granular solids, dimensionless;
F = Friction loss (lb force)/(sq ft)†
F_v = Friction loss, number of velocity heads, dimensionless;
g_c = Conversion factor, 32.17 (lb mass/lb force) (ft/sec²);
K_1, K_2 = Constants, dimensionless;
L = Length of straight horizontal pipe or depth of bed of granular solids in direction of flow, ft;
$(L/D)_e$ = Length of straight pipe expressed as number of pipe diameters, for which pressure drop is one velocity head (i. e., for which $\Delta p_v = 1$), dimensionless;
p_v = Velocity head, (lb force)/(sq ft);
Δp = Pressure drop, (lb force)/(sq ft);
Δp_v = Pressure drop, number of velocity heads, dimensionless;
R_e = Reynolds number, dimensionless = $(DV\rho/\mu)$ for flow through pipes, orifices, nozzles, or venturis; $D_cV_{max}\rho/\mu)$ for flow across tube banks; $(D_pV\rho/\mu)$ for flow through beds of granular solids;
V = Average fluid velocity, (ft/sec);
V_{max} = Maximum average fluid velocity in flow across tube banks, (ft/sec);
ρ = Fluid density, (lb mass)/(cu ft);
μ = Fluid viscosity, (lb mass)/(ft) (sec) = centipoises × 1488;
a = Ratio of areas, dimensionless—a value less than unity.

†Friction loss is often defined as an energy loss per unit mass of fluid, having the dimensions (ft-lb force)/(lb mass). This definition of friction loss is equivalent to the quotient F/ρ.

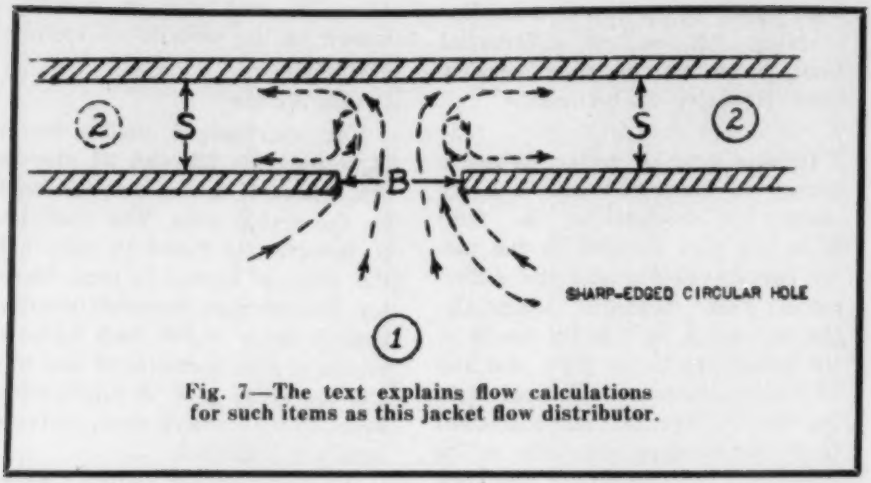

Fig. 7—The text explains flow calculations for such items as this jacket flow distributor.

ance for frictional losses and an allowance for the contraction of the stream. If the equations were based on the velocity or area at the vena contracta, rather than on the orifice area, the coefficient C would be practically the same as for a nozzle, i.e., 0.99, indicating that the frictional pressure loss corresponds to only about 2 per cent of the differential head. The fluid area at the vena contracta, however, is about 62 per cent of the orifice area, so that when the equations are based on orifice area, the effective coefficient, C, must be substantially the product of 0.99 and 0.62. Thus, contrary to a general misconception that an orifice is less efficient than a nozzle because the discharge coefficient is 0.99 for a nozzle and 0.61 for an orifice, an orifice merely behaves like a nozzle with a throat area of 0.62 that of the orifice.

It follows from Equation 22 that for orifice to pipe diameter ratios of less than 0.3, the differential head for vena contracta taps is substantially one velocity head based on the vena contracta area and 2.7 velocity heads based on the orifice area, since the velocity of approach correction is negligible in this case.

Partial recovery of pressure takes place following both an orifice and a nozzle. Such recovery is substantially complete at a distance of four pipe diameters downstream from the orifice or nozzle. The overall pressure drop across an orifice or nozzle for conditions of fully recovered head (which also corresponds to the pressure differential for an orifice or nozzle with pipe taps) can be calculated from a momentum balance, and is very closely approximated by

$$\Delta p_v = \left[\left(\sqrt{\frac{1+a^2C^2-a^2}{a^2C^2}}\right)-1\right]^2 \quad [24]$$

where Δp_v is expressed as number of pipe velocity heads; a is the ratio of nozzle or orifice area to pipe area; and C is the respective discharge coefficient for the nozzle or orifice with vena contracta taps (0.99 for a nozzle, 0.61 for a sharp-edged orifice). In order to obtain a given differential head for a fixed flow rate, a nozzle must have a throat area of 0.62 times that of a sharp-edged orifice, and it can be shown from Equation 24 that the recovered head or overall permanent loss will be the same, in this case, for both the nozzle and orifice.

Estimation of Pressure Drop or Friction Loss

In each of the previous examples, an interpretation in terms of velocity head has been presented to give the reader a semi-quantitative conception of the pressure drop in terms of the physical flow pattern.

Cases for which no actual experimental data are available frequently arise in practice, and it is up to the designer to estimate the pressure drop or obtain the required data by laboratory measurements. By visualizing the flow pattern that is apt to occur in such cases, it should be possible for the reader to make a reasonable estimate of the pressure drop for turbulent flow by applying the velocity head concept in a manner similar to the analyses presented in the previous paragraphs. Two further examples will be cited to illustrate the method for making such estimates.

Considering the flow through a sharp welded 90 deg bend, formed by the intersection of two equal cylinders, it is to be expected that the fluid loses its initial kinetic energy by impact at the bend and the kinetic energy required to permit flow out of the bend must be supplied from the pressure energy of the gas. Thus, the pressure drop (or friction loss) would be expected to be 1.0 velocity head. This is in good agreement with actual data. Table 3 (page 265, May HPAC) indicates a loss of 1.3 velocity heads for a square 90 deg screwed fitting. The additional 0.3 velocity head in this case is due largely to the expansion and contraction losses encountered in a screwed fitting.

Fig. 7 is a sketch of an element of a type of flow distributor sometimes encountered in practice for which no data appear to be available. The fluid, after passing through a sharp-edged distributor hole or orifice of diameter B impinges upon a back-up plate (which may actually correspond to a jacket wall) spaced a distance S behind the orifice plate, which deflects the stream laterally as indicated in Fig. 7. The fluid in passing through the sharp-edged hole contracts to a "vena contracta" as in the case of the sharp-edged orifice. The kinetic energy represented by the velocity head at the vena contracta is then substantially lost by impingement on the back-up plate. In order to develop the velocity for lateral movement through the cylindrical area πBS between the plates at the edge of the hole, pressure energy must also be converted into velocity energy. This would correspond to one velocity head based on the area πBS. Since the lateral expansion radially away from the hole is relatively abrupt, this kinetic energy is largely dissipated as heat by turbulence. The overall pressure drop from *1* to *2* may thus be visualized as the sum of the velocity head corresponding to the vena contracta of the stream following the distributor hole and the velocity head corresponding to the area πBS. If the distributor plate containing the hole is relatively thin compared to the hole

diameter (on the order of ½ or less), the contraction will be the same as for a sharp-edged orifice and the area of the fluid stream at the vena contracta will be 0.61 of the hole area, $\pi B^2/4$. Thus, the pressure drop would be expected to be 2.7 velocity heads based on the hole area (since this is the equivalent of 1.0 velocity head based on the vena contracta) plus 1.0 velocity head based on the cylindrical area πBS. Recent unpublished measurements indicated that this prediction checked actual data within ± 10 per cent. These tests were made with air using a 16 ga plate with a sharp-edged orifice of 0.8 in. diameter. The plate spacing, S, was varied from infinity (i.e., no back-up plate employed) to 0.075 in. and the air velocity based on the 0.8 in. diameter hole was varied from 25 to 150 ft/sec corresponding to a Reynolds number range based on the hole area of from 10,000 to 60,000. Two back-up plates, 2⅛ in. and 3¾ in. diameter, were tested, but both gave substantially the same results.

It should be pointed out that the flow pattern and mechanism in these two examples has possibly been oversimplified in order to enable a pressure drop estimate to be made. For example, in the case of the distributor plate, there is probably some recovery of kinetic energy upon impact following passage of the fluid through the hole and some contraction of the fluid must occur as it passes through the area πBS. These two factors, however, tend to counteract each other in so far as overall pressure drop is concerned. Also, if the plate spacing, S, is small compared to the hole diameter, B, the jet contraction following the hole is probably not complete before impingement takes place. In this case, however, the pressure drop across the hole is a relatively small portion of the overall pressure drop. The fact that the simplified flow pattern checked so closely with experiment must be attributed to some extent to a coincidence resulting from a compensation of factors in the actual flow pattern. Thus, in making estimates of this type, due allowances in the form of safety factors should be made. The magnitude of these factors will vary with each case, but some idea of this magnitude can be obtained by considering the possible extreme flow patterns. Usually such estimates of pressure drop can be relied on to better than ± 50 per cent.

Numerical Examples

In order to familiarize the reader further with the application of the velocity head method to actual pressure drop calculations, the following numerical examples are presented.

Example 1: A 2 in. Schedule 40 pipe is handling 50 gal/min of water. What is the pressue drop across 200 ft of this pipe containing 12 standard ells and one fully open globe valve?

Solution:

Pipe diameter = 2.067 in.

Pipe area = (0.785) $(2.067)^2/144 = 0.0233$ sq ft.

Pipe velocity = $V = (50)/(7.48)(60)(0.0233) = 4.78$ ft/sec.

Velocity head in pipe = $(4.78)^2/(2)(32.17) = 0.36$ ft of water.

Assume $(L/D)_v = 40$ (actually a calculation of the Reynolds number and corresponding friction factor would show $(L/D)_v = 44$).

Pressure Drop:

Through pipe = $(200)(12)/(2.067)(40) = 29.0$ pipe velocity heads.

Through ells = (12) (0.74) (from Table 3, page 265, May HPAC) = 8.9 pipe velocity heads.

Through globe valve = (1) (9.0) (from Table 3) = 9.0 pipe velocity heads.

The total pressure drop is thus 46.9 pipe velocity heads, or $46.9 \times 0.36 = 16.9$ ft of water.

The above calculation does not allow for any inlet or outlet losses from the pipe, which will depend on configuration at the ends of the section considered and will be zero if the section considered is but a portion of a longer, continuous length of piping.

Example 2: A 10.00 in. standard sharp-edged orifice in a 20 in. diameter duct with vena contracta taps indicates a differential reading of 3.5 in. water when handling air at 20 C and atmospheric pressure. What is the air flow rate?

Solution:

$a = (10/20)^2 = 0.25$; assume $C = 0.61$.

Orifice differential = $[1 - (0.25)^2]/(0.61)^2 = 2.52$ velocity heads based on orifice area.

Therefore velocity head based on orifice area = $(3.5)/(2.52) = 1.39$ in. of water.

From Fig. 1 (page 180, April HPAC), velocity based on orifice area is 78.4 ft/sec.

Orifice area = $(0.785)(10/12)^2 = 0.545$ sq ft.

Therefore air handled = (0.545) (78.4) (60) = 2560 cu ft/min.

Fig. 3 (page 182, April issue)

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Flow Through Beds of Granular Solids

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Nozzles, Orifices, Pitot Tubes, Venturis

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could also be used in place of the last two steps. Thus, for a 10 in. duct, (ft/sec)/(cu ft/min) = 0.0306. Therefore air rate = (78.4)/(0.0306) = 2560 cu ft/min.

Epilogue

In conclusion, the author must apologize for the numerous cases where scientific accuracy and rigor have been discarded for the sake of simplicity. This paper is intended largely as a guide to a physical conception or visualization of otherwise seemingly complex fluid phenomena, rather than as a survey of available pressure drop data, and this sacrifice was deliberate. For many purposes the approximations presented will be entirely adequate, and an attempt has been made to point out the limits of accuracy in each case. Where more accuracy is required, the reader can supply the necessary refinements by reference to the cited literature. The velocity head method of calculation can still be retained, however, and should serve to guide the designer away from the possible errors that lurk in any calculation in the form of units, decimal points, and general interpretation. For cases where no data are available, the interpretations presented should serve as means of obtaining reasonable estimates in place of a possible temptation to resort to intuitive guessing.

URGES POSTWAR DISTRICT HEATING

Robert L. Fitzgerald vice-president of the Duluth Steam Corp., urges widespread adoption of public utility central steam heating for all types of buildings in a talk given earlier this year and since published in a booklet entitled A Twenty Billion Dollar Postwar Business, which is copyrighted by the author. In his discussion, Mr. Fitzgerald assembles many arguments for the use of district steam heating, and says that—in addition to its engineering advantages—it will "provide a constructive use for the rapidly accumulating long term investment funds which are now available at the lowest interest rate in American industrial history, provide a 20 billion dollar construction program to cushion the impact of unemployment in the postwar period, and provide a proper field of activity for the promotional talents of those returning from the fields and seas of battle with a desire to perform a real service."

Technical advantages of district heating cited by Mr. Fitzgerald include the removal of "the greatest single fire hazard" from homes and buildings; the placing in every building of a supply of high pressure steam, which he says is the "most effective fire extinguisher known"; the providing of a means of completely automatic heat with no ash removal problem; making available an ever-ready supply of high pressure steam for large and small commercial and industrial process use; and providing a fireless means of cooking, hot water heating, laundry drying and ironing.

Large central boiler plants have perfected smokeless operation, says Mr. Fitzgerald, and adoption of his suggestion would therefore eliminate the city smoke nuisance—the colossal property damage of which has long been recognized, and which has been related by public health authorities to respiratory diseases and fatalities. Extensive smoke blighted city areas have created a heavy municipal operating expense and at the same time have reduced tax revenues because of reduced tax values, he states. Slum clearance and rebuilding scheduled as postwar work will be "completely wasted, from a social viewpoint," in his opinion, unless central steam utility service is available to clear up the smoke density which has degraded these areas.

Mr. Fitzgerald insists that the heating job is too big to be done on a national scale with any fuel other than coal, although oil "could almost do it if an unlimited supply at the right price over a long period were in sight."

In discussing the economics of his proposal, Mr. Fitzgerald says that central boiler plant efficiencies of 85 per cent are quite common and that methods and materials for distributing steam in underground pipe lines at 250 psi pressure are available. Thanks to such developments, he says, central steam public utilities "to completely serve all communities regardless of size can be made economically sound and profitable operations."

In a supplement to his paper, Mr. Fitzgerald sets up in tabular form a central station plant and distribution system for a "typical city" of 35,000 population. It provides for a 7000 hp boiler plant and 47 miles of distribution lines, to serve 7000 homes and the commercial and industrial steam needs of the city. It requires an investment of $4,745,000, produces a gross revenue of $1,392,000 per year, on the basis of the retail coal cost when doing the heating job by individual plants. The operation shows an annual earning, after interest, taxes and depreciation, of $52,480, which if used with the depreciation reserve to retire bonds, would liquidate the entire investment in 24 years. If the operation is by a municipality free from taxes and financed with 2 per cent municipal bonds, the investment could be retired in about 12 years from operating income and depreciation reserve, his figures indicate.

That municipal authorities are including central station heating in their postwar thinking is indicated by announcements received recently from two communities, one of which has engaged a firm of consulting engineers to make a complete study of a proposal to expand an existing city-owned steam plant and the other of which has awarded a franchise for a central station heating system. During the war, district heating has expanded with the increased general industrial and commercial activity and with wartime fuel limitations, and it is understood that the district heating industry is hopeful of maintaining its gains and making further progress. Thus, Mr. Fitzgerald's paper, stressing as it does his arguments in favor of central station heating, appears to be a timely discussion of at least one view of the case.

Sam Lewis' Page

FIGURING SEASONAL COST OF HEATING A BUILDING

IN THIS regular feature, informal comment on heating, piping, and air conditioning problems is given by Samuel R. Lewis, consulting mechanical engineer, and a member of HPAC's board of consulting and contributing editors. This month, he discusses an extensive memorandum, submitted by Roger A. Parsons, for comment, on computing the seasonal cost of heating a building. Mr. Parsons' main contentions are that enough data of sufficient accuracy to provide for a reasonably complete heating analysis of the vast majority of buildings are available, but that recommended methods for using data involving the numerous factors affecting heating requirements provide for only a few of these factors, and do not provide correctly for all of these.

A READER of HPAC, Roger A. Parsons—evidently interested in metered central station heating—has voiced criticism of the methods suggested in the Guide of the American Society of Heating and Ventilating Engineers for computing the seasonal cost of heating a building. He suggests, in a comprehensive memorandum on the subject, which he has sent the editor, "a complete building heating analysis," and groups the factors that determine the heating requirements of any building in three major categories, as follows: (1) Heat loss to the outside, influenced by location of the building. (2) Resistance to heat loss, influenced by quality of construction. (3) Character of the heating system and quality of its operation.

I do not quarrel with these three classifications. Mr. Parsons states that the presence or absence of automatic temperature control will affect seriously any attempt to compute the seasonal cost of heating, and believes that air leakage is largely a matter of guesswork. I agree with him in these particulars. He cites the case of the Mutual building, Lansing, Mich., in which computation of infiltration by Guide methods shows 18.5 per cent of the total loss. He figures that the seasonal heat loss due to infiltration is only 6.2 per cent of the total seasonal heat loss or about one-third of that indicated by the Guide method, but does not disclose how he determined this.

It is difficult indeed to determine the seasonal amount of infiltration through building structures. One way, for example, would be to have the building walls impervious to air passage and to place an airtight cover over every window opening; this cover funneling all air leakage through each entire opening to an accurate meter recording the rate of air flow throughout the season. The Guide method for computing infiltration through cracks around windows and doors assumes some definite crack width and a definite wind velocity. It is, of course, obvious that the wind pressure on the shell of any building is not constant, and that inward leakage of air on the windward side plus outward leakage of air on the leeward side of any building must vary widely. It is obvious also that the width of air leakage crack changes in response to quality of maintenance of windows and door closures even with the same original type of construction and that it must vary in a wide range as age and weather take their toll.

Ventilation Must Be Allowed For

Mr. Parsons suggests that the Guide methods, which might be acceptable for computing the capacity of a heating plant for original installation, are not acceptable for computing the seasonal fuel demand of the same building. His position in this regard is tenable to the extent that average rather than maximum rates of heat loss must determine the seasonal total. Since many buildings are ventilated mechanically, though the ventilation apparatus may be operated intermittently, and since the ventilating system so operated may be applied only to certain rooms in the building, allowances for such ventilation can hope to approach accuracy only following minute analysis of every building.

Mr. Parsons seems to recognize that air leakage in buildings is invariably between the limits of 5 per cent and 35 per cent of the total heating load. I do not think he means to accept this statement. I do not accept it as applying to the seasonal rate of heat loss. In practice, for average design purposes, we seem to get along pretty well if we allow for infiltration by adding 30 per cent to the design transmission loss of all exposed glass and walls.

It is definitely impracticable to compute accurately the cost of fuel for any ventilated building unless the hours during which the ventilating equipment is operated at a definite rate are known, and unless the intake and outlet openings for the ventilating system are closed tightly during the hours when the apparatus is not in service.

Mr. Parsons suggests that compensation should be made of the seasonal heat gain from the sun and from the illuminating arrangements and from the bodily heat of the occupants. This heat reception undoubtedly does influence the seasonal amount of heat that must be supplied, but like the computation for window crack leakage, such figures are capable of wide variation and I think they are undependable. For example, Mr. Parsons mentions solar heat 40 per cent of possible, and 100 per cent possible occupancy by people. Our standard computa-

tions for maximum heat loss per hour can easily be modified by an overall factor to compensate for such seasonal gains.

Annual Heating Load

Mr. Parsons' conclusions for the above-mentioned building in Lansing, apparently worked backward from the actual metered rate, divide the annual load into the following percentages:

Glass	35.5
Walls	33.5
Ventilation	16.6
Infiltration	5.7
Roof	3.6
Walls below grade	1.4
Electricity	3.7
	100.0

It seems to me that any watts delivered into the building must result in some heat delivered into the building, and the tabulation indicating that the fuel cost must be increased if electric heat and power are consumed, is confusing. If Mr. Parsons means that 3.7 per cent of the total heat used in this building was furnished by electricity, then what has become of the heat furnished by the sun and by the people?

My impression is that the seasonal heating load for buildings may most satisfactorily be based first on the design maximum heating demand, modified then by factors that will allow for average conditions—such as wind and hours of occupancy.

The three major categories mentioned by Mr. Parsons all seem to be inherently included in the information developed in the design computations.

It is not customary in the basic design of most heating plants to reduce the capacity because of expected solar heat reception, nor is it customary to reduce the capacity of the plant on account of heat expected from electric lights or power. Usually the buildings must be heated prior to occupancy. There seems to me to be some intelligence in a formula based on the design heat demand per hour, multiplied by the hours per heating season for the locality, multiplied by a percentage that accounts for hours when fuel or its equivalent is not required or during which the fuel consumption rate is reduced. Then the computer may deduct some guess as to the heat equivalent of the manufacturing or process load.

From the data given in Mr. Parsons' memorandum, it is not easily practicable to learn what was the design hourly heat loss from the building to which he refers. It would be indeed interesting to know what percentage of this hourly heat loss multiplied by the hours per heating season will result in the heat equivalent of the 3,475,000 lb of steam that he states were condensed.

Uses Percentage of Design Load

I have estimated the annual heat demand of many buildings on the basis of a percentage of the design load multiplied by seasonal hours, ignoring solar reception, and have found the results reasonably accurate when compared with the actual seasonal input as metered. I long ago abandoned the Guide method of attempting to compute design air leakage by guessing at the crack width and have used, instead, a percentage of the computed loss from exposed glass and wall areas.

Mr. Parsons is to be commended for voicing the need for more research, and for courage in exposing his computations for comment.

REMA ELECTS OFFICERS, COMMENDS WPB

F. J. Hood, vice-president of the Ansul Chemical Co., was elected president last month of the Refrigeration Equipment Manufacturers Association at a meeting of the new board of directors. He succeeds Arthur B. Schellenberg, president of the Alco Valve Co., as head of the association which comprises more than 75 members representing the refrigeration and air conditioning industries.

Other new officers are H. F. Spoehrer, Sporlan Valve Co., vice-president; Edward M. Flannery, Bush Mfg. Co., secretary, and J. A. Strachan, Weatherhead Co., treasurer. R. Kennedy Hanson continues as executive secretary with offices in the association's headquarters in Pittsburgh.

The directors voted that the retiring president, Mr. Schellenberg, send a letter to J. A. Krug, WPB chairman, commending WPB on the manner in which materials have been allotted in an unbiased way to the refrigeration and air conditioning industries.

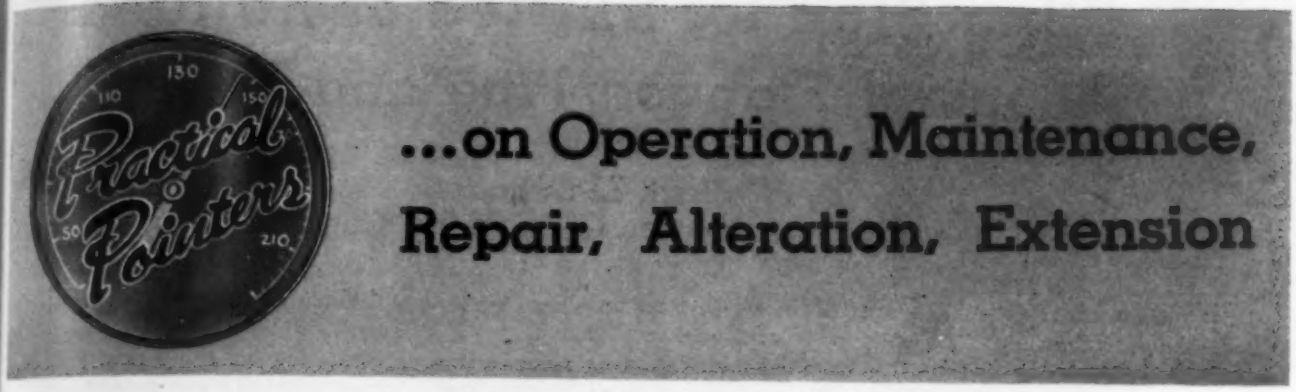
To foster the interests of the entire field of refrigeration and air conditioning during the reconversion and postwar periods, a public and trade education program was launched last month by the REMA. In announcing the program, Mr. Hanson said that it is planned to help meet the needs of end products manufacturers, as well as parts producers, distributors, dealers, engineers, and servicemen. The need for maintaining existing equipment during the period when demand will continue to exceed supply, while building up a maximum acceptability among prospective users to reach its climax at the time industry will be ready for new markets, will be emphasized.

Uncle Sam
Wants You
to Fight
Waste!
SAVE FUEL

GUILBERT HEADS PFMA

H. M. Guilbert, of the B. F. Sturtevant Co., was elected president of the Propeller Fan Manufacturers Association, and E. C. Englert, Hartzell Propeller Fan Co., was named vice-president, at the group's annual meeting held earlier this year. The secretary-treasurer of the PFMA is V. C. Shetler, 2-255 General Motors Bldg., Detroit 2.

The association has issued a leaflet featuring its air delivery tables and showing a diagram of the test setup for axial blowers or exhausters without duct.



How Ventilating and Heating System at Big Industrial Plant Is Operated

THE ARTICLE entitled Underground Ducts Supply Heated Air to Floor Level Grilles at Big Plant, by H. K. Hicks, on pages 243-245 of the May HPAC, describes this heating and ventilating system very well. This system was put in operation in January 1942 and has been used both winter and summer—in the winter for heating and ventilation, and in the summertime merely as an outdoor air inlet and ventilating system.

We have been directly responsible for the maintenance and operation of this system. So far, the system has given us very little trouble, mechanically or electrically. As Mr. Hicks stated in his article, the air in the existing shop was very bad. Various means had been tried to correct this condition without much success. In the new shop with this new system in operation, we get almost a clear atmosphere. The only error that was made in design was in the area of the floor ducts. It is our belief that if these ducts had been made larger, with a consequent reduction in air velocity, the system would have been a trifle more satisfactory.

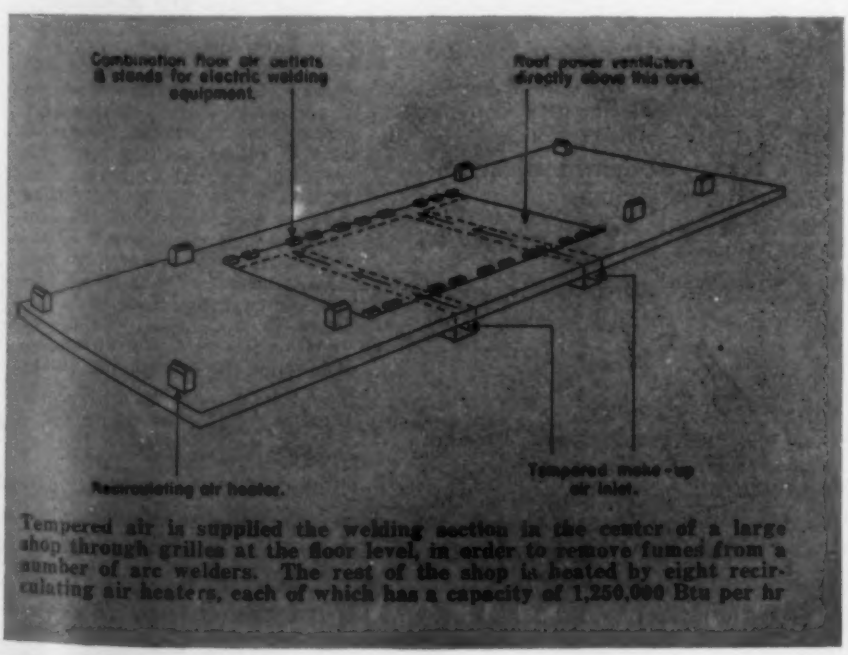
Ventilating Air Temperature Raised

With an air temperature of 70 F, if it is necessary for a man to work close to one of these ducts, he has a feeling of being cold due to the air blowing on him. It has therefore been necessary to raise the air temperature to around 76 to 77 F to overcome this cold feeling. Other than that, we have had no complaint from the workmen.

In very cold weather, it has been necessary to raise the temperature of this ventilating air to approximately 80 F because the eight 1,250,000 Btu per hr gas fired heaters were not of sufficient capacity to supply the heat lost by radiation from the building. This increase in capacity did not in any way affect the overall operation of the ventilating system. We have very seldom operated the system with all four axial flow fans in each of the two fan rooms in operation. Under normal operating conditions with our normal number of welders working, three fans in each fan room have given us sufficient air supply to keep the atmosphere clear.

Control System Works Well

The modulating temperature control system has functioned very well. We have practically no variation in air temperature. The safety features of the control system have functioned at all times. We, of course, have had power failure at various times, and in each instance the gas was shut off immediately so that no excessive temperature was created. We make a periodic check of the safety controls by shutting off the motors without turning off the gas to be sure that the gas will shut off when the power is off the motors.—HENRY S. HALL, fuel engineer, Lukens Steel Co.


Combination floor air outlets & stands for electric welding equipment.
Roof power ventilators directly above this area.
Recirculating air heater.
Tempered make-up air inlet.

Tempered air is supplied the welding section in the center of a large shop through grilles at the floor level, in order to remove fumes from a number of arc welders. The rest of the shop is heated by eight recirculating air heaters, each of which has a capacity of 1,250,000 Btu per hr

Table Giving Angles and Direction for Shifted Drilling in Pipe Flanges

←*Counterclockwise Rotation* **American Standard Flanges Except as Noted** *Clockwise Rotation*→

Drilling Plan for Shifted or Rotated Positions of Flanged Pipe and Fittings

By Wallace L. Saunders
Mechanical Draftsman, Glen Alden Coal Co.

IN THE PERFORMANCE of my duties as a mechanical draftsman, I have frequently been faced with the difficult problem of shifting the drilling on the flanges of pipe and pipe fittings, in connection with piping layouts for pump installations in and around various mines. The answer one may assume to be correct for problems of this kind very often is wrong and there is sure to be an argument if someone else is consulted.

Elisha J. Falloon, hydraulic engineer for the Glen Alden Coal Co., and I have developed the accompanying table to give the direction and the amount of shift in degrees from the vertical centerline for various pipe standards. It is our feeling that it should be useful in connection with a variety of piping installations.

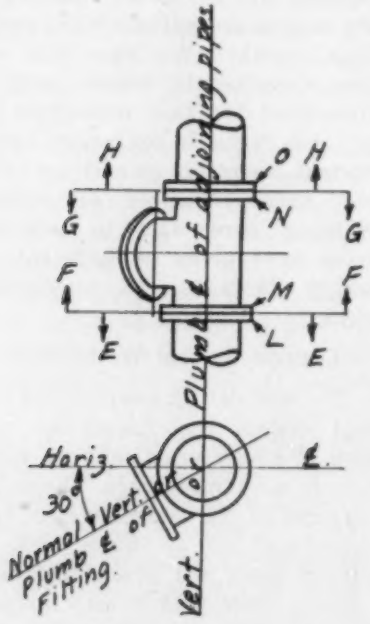


Fig. 1

Assume a combination such as Fig. 1, where flanges *M* and *N* of a tee are turned to a position where standard drilling would be out of register with standard drilling of flanges *L* and *O* of adjoining pipes, flanges *L* and *O* being in harmony with the vertical or plumb centerline as shown in Fig. 2.

Consider Fig. 2 as representing flange *L* viewed as per section *E-E*, or flange *O* viewed as per section *H-H*, with drilling arranged symmetrically with respect to the vertical or plumb centerline; and consider Fig. 3 as representing flange *M* viewed as per section *F-F*, or flange *N* viewed as per section *G-G*, with drilling pattern to be shifted or rotated clockwise, or counterclockwise, by amount necessary to register with drilling in flanges *L* and *O*.

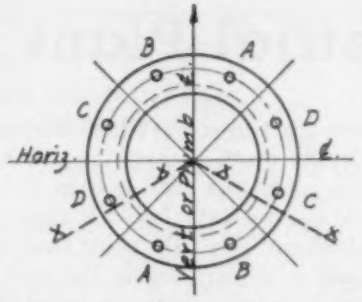


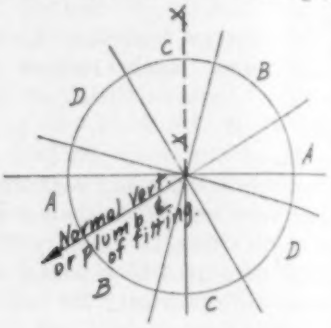
Fig. 2—Use this diagram to represent a flange whose drilling symmetrically straddles vertical or plumb centerline—for instance, flanges *L* or *O* in Fig. 1. Each sector— *A*, *B*, *C*, and *D*—is 45 deg

Now the total angle in degrees through which flanges *M* and *N* are to be rotated and the direction of this rotation are illustrated in Figs. 3 and 4, and will show which sector (A, B, C, or D) is to be used in the accompanying table.

Example

A 14 in. tee, 250 lb pressure, 20 holes, is to be rotated to the left 30 deg below the horizontal centerline. Drilling on flanges *M* and *N* to be shifted as required.

Answer—View flange *M* through section *F-F*, see Fig. 3. Now, since this fitting has been turned downward 30 deg below the horizontal centerline to the left (which is the centerline of its normal drilling and plumb centerline), we must rotate the plumb centerline of the diagram 30 deg below the horizontal centerline to the left. Line *X-X* represents the plumb centerline of flange *L*, which falls in sector *C*, as shown in Fig. 3. By referring to the table under sector *C* and opposite 30 deg for such a case (14 in., 250 lb pressure), it will be seen that the net shift of drilling required in flange *M* will be 6 deg counterclockwise.



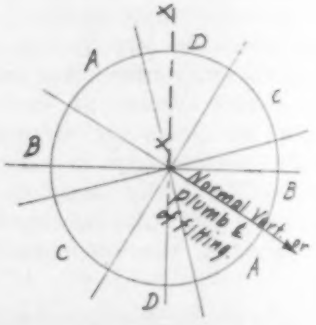


Fig. 3 (above) and Fig. 4 (below)—These two diagrams are the same as Fig. 2, having been rotated to represent flanges *M* and *N* whose drilling does not straddle vertical or plumb centerline. The course the fitting takes when looking at the face of its flange is indicated by the direction of the arrow. All sectors remain in the same sequence and direction with respect to the arrow. Line *X-X* represents vertical or plumb centerline of companion flange

Drilling of flange *N* as viewed through section *G-G* will have to be shifted 6 deg clockwise as this puts line *X-X* in sector *D* of Fig. 4.

It is apparent from the above de-

Table Giving Angles and Direction for Shifted Drilling in Pipe Flanges

American Standard Flanges Except as Noted

← Counterclockwise Rotation									Clockwise Rotation →
	125 Lb. Press.	Not Standard	125 Lb. Press.	125 Lb. Press.	125 Lb. Press.	125 Lb. Press.	125 Lb. Press.	125 Lb. Press.	125 Lb. Press.
Angles	1°-1½°-2° 2½°-3°		3½° to 8° Inc.	10°-12°-14°	16°-18°	20°-22°-24°	None	30°	36°
A or B	250 Lb. Press.		250 Lb. Press.	250 Lb. Press.	250 Lb. Press.	250 Lb. Press.	250 Lb. Press.	250 Lb. Press.	250 Lb. Press.
C or D	1°-1½°		2° to 5° Inc.	6°-7°-8°	10°-12°	14°-16°	18°-20°-22°-24°	30°	36°
	4 Holes	6 Holes	8 Holes	12 Holes	16 Holes	20 Holes	24 Holes	28 Holes	32 Holes
	90° Apart	60° Apart	45° Apart	30° Apart	22.5° Apart	18° Apart	15° Apart	12.86° Apart	11.25° Apart

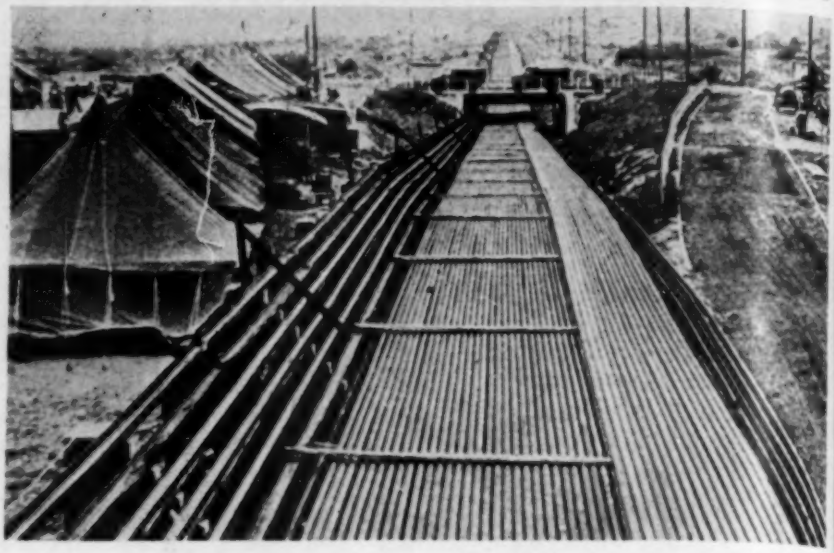
1. Degree	1°	1°	1°	1°	1°	1°	1°	1°
1.5	B 1.5 A	B 1.5 A	B 1.5 A	B 1.5 A	B 1.5 A	B 1.5 A	B 1.5 A	B 1.5 A
2.	or 2. or	or 2. or	or 2. or	or 2. or	or 2. or	or 2. or	or 2. or	or 2. or
2.5	D 2.5 C	D 2.5 C	D 2.5 C	D 2.5 C	D 2.5 C	D 2.5 C	D 2.5 C	D 2.5 C
3.	3.	3.	3.	3.	3.	3.	3.	3.
3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
4.	4.	4.	4.	4.	4.	4.	4.	4.
4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
5.	5.	5.	5.	5.	5.	5.	5.	5.
5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
6.	6.	6.	6.	6.	6.	6.	6.	A 5.25 B
6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	or 4.75 or
7.	7.	7.	7.	7.	7.	7.	A 5.86 B	C 4.25 D
7.5	7.5	7.5	7.5	7.5	7.5	On 7.5 Seam	or 5.36 or	3.75
8.	8.	8.	8.	8.	8.	A 7. B	C 4.86 D	3.25
8.5	8.5	8.5	8.5	8.5	8.5	or 6.5 or	4.36	2.75
9.	9.	9.	9.	9.	On 9. Seam	C 6. D	3.86	2.25
9.5	9.5	9.5	9.5	9.5	A 8.5 B	5.5	3.36	1.75
10	10.	10.	10.	10.	or 8. or	5.	2.86	1.25
10.5	10.5	10.5	10.5	10.5	C 7.5 D	4.5	2.36	0.75
11	11.	11.	11.	11.	7.	4.	1.86	0.25
11.5	11.5	11.5	11.5	A 11. B	6.5	3.5	1.36	B 0.25 A
12	12.	12.	12.	or 10.5 or	6.	3.	0.86	or 0.75 or
12.5	12.5	12.5	12.5	C 10. D	5.5	2.5	0.36	D 1.25 C
13.	13.	13.	13.	9.5	5.	2.	B 0.14 A	1.75
13.5	13.5	13.5	13.5	9.	4.5	1.5	or 0.64 or	2.25
14.	14.	14.	14.	8.5	4.	1.	D 1.14 C	2.75
14.5	14.5	14.5	14.5	8.	3.5	0.5	1.64	3.25
15.	15.	15.	15.	On 15. Seam	3.	0.	2.14	3.75
15.5	15.5	15.5	15.5	A 14.5 B	2.5	B 0.5 A	2.64	4.25
16.	16.	16.	16.	or 14. or	2.	or 1. or	3.14	4.75
16.5	16.5	16.5	16.5	C 13.5 D	1.5	D 1.5 C	3.64	5.25
17.	17.	17.	17.	13.	1.	2.	4.14	5.5
17.5	17.5	17.5	17.5	12.5	0.5	2.5	4.64	A 5. B
18.	18.	18.	18.	12.	0.	3.	5.14	or 4.5 or
18.5	18.5	18.5	18.5	11.5	B 0.5 A	3.5	5.64	C 4. D
19.	19.	19.	19.	11.	or 1. or	4.	6.14	3.5
19.5	19.5	19.5	19.5	10.5	D 1.5 C	4.5	A 6.22 B	3.
20.	20.	20.	20.	10.	2.	5.	or 5.72 or	2.5
20.5	20.5	20.5	20.5	9.5	2.	5.5	C 5.22 D	2.
21.	21.	21.	21.	9.	1.5	6.	4.72	1.5
21.5	21.5	21.5	21.5	8.5	1.	6.5	4.22	1.
22.	22.	22.	22.	8.	0.5	7.	3.72	0.5
22.5	22.5	22.5	On 22.5 Seam	7.5	0.	4.5	On 7.5 Seam 3.22	0
23.	23.	23.	A 22. B	7.	B 0.5 A	5.	A 7. B	2.72	B 0.5 A
23.5	23.5	23.5	or 21.5 or	6.5	or 1. or	5.5	or 6.5 or	2.22	or 1. or
24.	24.	24.	C 21. D	6.	D 1.5 C	6.	C 6. D	1.72	D 1.5 C
24.5	24.5	24.5	20.5	5.5	2.	6.5	5.5	1.22	2.
25.	25.	25.	20.	5.	2.5	7.	5.	0.72	2.5
25.5	25.5	25.5	19.5	4.5	3.	7.5	4.5	0.22	3.
26.	26.	26.	19.	4.	3.5	8.	4.	B 0.28 A	3.5
26.5	26.5	26.5	18.5	3.5	4.	8.5	3.5	or 0.78 or	4.
27.	27.	27.	18.	3.	4.5	On 9. Seam	3.	D 1.28 C	4.5
27.5	27.5	27.5	17.5	2.5	5.	A 8.5 B	2.5	1.78	5.
28.	28.	28.	17.	2.	5.5	or 8. or	2.	2.28	5.5
28.5	28.5	28.5	16.5	1.5	6.	C 7.5 D	1.5	2.78	A 5.25 B
29.	29.	29.	16.	1.	6.5	7.	1.	3.28	or 4.75 or
29.5	29.5	29.5	15.5	0.5	7.	6.5	0.5	3.78	C 4.25 D
30.	30.	On 30. Seam	15.	0	7.5	6.	0	4.28	3.75
30.5	30.5	A 29.5 B	14.5	B 0.5 A	8.	5.5	B 0.5 A	4.78	3.25
31.	31.	or 29. or	14.	or 1. or	8.5	5.	or 1. or	5.28	2.75
31.5	31.5	C 28.5 D	13.5	D 1.5 C	9.	4.5	D 1.5 C	5.78	2.25
32.	32.	28.	13.	2.	9.5	4.	2.	6.28	1.75
32.5	32.5	27.5	12.5	2.5	10.	3.5	2.5	A 6.08 B	1.25
33.	33.	27.	12.	3.	10.5	3.	3.	or 5.58 or	0.75
33.5	33.5	26.5	11.5	3.5	11.	2.5	3.5	C 5.08 D	0.25
34.	34.	26.	11.	4.	A 11. B	2.	4.	4.58	B 0.25 A
34.5	34.5	25.5	10.5	4.5	or 10.5 or	1.5	4.5	4.08	or 0.75 or
35.	35.	25.	10.	5.	C 10. D	1.	5.	3.58	D 1.25 C
35.5	35.5	24.5	9.5	5.5	9.5	0.5	5.5	3.08	1.75
36.	36.	24.	9.	6.	9.	0.	6.	2.58	2.25
36.5	36.5	23.5	8.5	6.5	8.5	B 0.5 A	6.5	2.08	2.75
37.	37.	23.	8.	7.	8.	or 1. or	7.	1.58	3.25
37.5	37.5	22.5	7.5	7.5	7.5	D 1.5 C	On 7.5 Seam	1.08	3.75
38.	38.	22.	7.	8.	7.	2.	A 7. B	0.58	4.25
38.5	38.5	21.5	6.5	8.5	6.5	2.5	or 6.5 or	0.08	4.75
39.	39.	21.	6.	9.	6.	3.	C 6. D	B 0.42 A	5.25
39.5	39.5	20.5	5.5	9.5	5.5	3.5	5.5	or 0.92 or	5.5
40.	40.	20.	5.	10.	5.	4.	5.	D 1.42 C	A 5. B
40.5	40.5	19.5	4.5	10.5	4.5	4.5	4.5	1.92	or 4.5 or
41.	41	19.	4.	11.	4.	5.	4.	2.42	C 4. D
41.5	41.5	18.5	3.5	11.5	3.5	5.5	3.5	2.92	3.5
42.	42.	18.	3.	12.	3.	6.	3.	3.42	3.
42.5	42.5	17.5	2.5	12.5	2.5	6.5	2.5	3.92	2.5
43.	43.	17.	2.	13.	2.	7.	2.	4.42	2.
43.5	43.5	16.5	1.5	13.5	1.5	7.5	1.5	4.92	1.5
44.	44.	16.	1.	14.	1.	8.	1.	5.42	1.
44.5	44.5	15.5	0.5	14.5	0.5	8.5	0.5	5.92	0.5
45.	On 45. Seam	15.	0	On 15. Seam	0	On 9. Seam	0	6.42	0

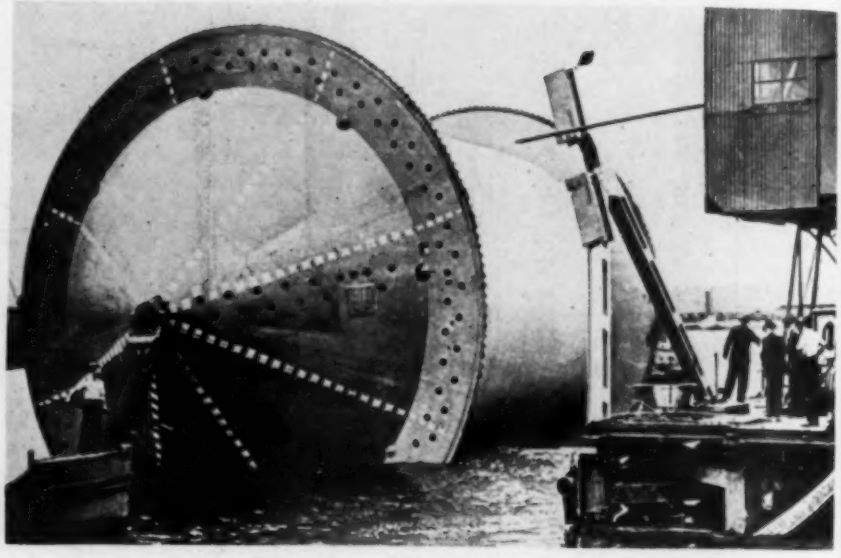
scription that both flanges of the tee must have the holes shifted; one in the opposite direction from the other, by the same amount, while flanges *L* and *O* remain as they are.

Although only one flange of a pair of flanges will have the drilling shifted, the question often arises as to what the direction and shift would be in the other flange if it were desired to make the shift here instead.

For this problem, let us consider flange *L*. The normal drilling of this would, of course, be as shown in Fig. 2, but since in this case it is to be made to harmonize with the normal drilling of flange *M*, which has had its drilling centerline rotated 30 deg downward from the horizontal centerline to the right (section *E-E*), it will fall in sector *C* of Fig. 2; so again we find from the table a 6 deg counterclockwise shift of drilling required. Likewise, for flange *O* a shift of 6 deg clockwise would be required, proving that either one of a pair of flanges would have the same shift and direction, since line *X-X* falls in sector *D*.

(Suggestion: A disc showing the sectors, as per Fig. 2, and a smaller disc with a radial line to one edge to represent *X-X*, may be riveted together so they will turn. Large disc = far flange. Small disc = near (companion) flange. With these it will be unnecessary to lay out the diagrams.)





ENGLISH CHANNEL PIPED FOR GAS

Shortly after the Allied invasion of Europe there arose the problem of supplying gas to the fighting forces. The use of tankers would involve too many ships, and there would always be the risk of running into enemy subs. Then, too, there would have to be many oil trucks to carry it from the ships to the troops. So Royal Engineers and navy men devised a plan to lay pipe lines in the Channel. Before the task began, pipe was stored in England in three-quarter mile lengths ready for winding on the giant drums which were towed across the Channel by the English navy . . . A huge drum is moved into position for loading steel pipe before being towed across the Channel to lay continuous lengths of pipe 70 miles long . . . British troops install a valve at Boulogne, France, for the first line. (British official photos, from Acme)

Heating, Piping & Air Conditioning

AMERICAN SOCIETY of HEATING and VENTILATING ENGINEERS

Journal Section

Effect of Air Movement on the Comfort Zone in Netherlands India

By C. J. Kip* and R. Courtice**
Brisbane, Australia

Introduction

IN TROPICAL and subtropical regions, it is highly desirable that man should live and work under conditions which lie within the limits of the comfort zone, in order to obtain maximum efficiency and a feeling of well-being. The limits of the comfort zone for still air for Netherlands India were previously determined by Mom and Wiesebron.[1] Conditions prevailing in many Javenese cities lie outside the comfort zone for a considerable part of each average day.

An effective temperature scheme was established for Netherlands India by Mom, Wiesebron, Courtice and Kip,[2] mainly applicable to the comfort zone and incorporating the effective temperature range 19 C-28 C (66.2 F-82.4 F). This was carried out in order to facilitate the present investigation of the effect of air movement upon the location of the comfort zone.

It is evident that the addition of air movement will facilitate the elimination of heat from the body by evaporation of sweat from the skin surface and by convection currents established in the air layer adjoining the skin surface. By the addition of air movement atmospheric conditions which previously lay above the limits of the comfort zone may produce a sensation of comfort.

Plan of Experiments

In this investigation, air velocities which could be used in offices, bedrooms and living rooms were obtained by means of electric fans. Only six subjects were used because these subjects had had considerable experience in evaluating comfort sensations and were found to be very sensitive to small changes in atmospheric conditions. The subjects were students and members of the staff of the laboratory and were of Dutch, British and Javanese nationalities. Two psychrometric rooms, described at length by Wiesebron[3] in a previous publication, were used. In room A, uniform air velocities of 60 and 120 cm/sec were obtained (118 and 236 fpm, respectively), using three electric fans, arranged by trial and error so as to give a uniform air velocity over all parts of the body of a subject standing within a circle of approximately 4 ft in diameter. The air velocity was calculated from readings taken by means of a kata thermometer hung at different levels and in different sectors of the above circumscribed area. Three relative humidities, 45, 60 and 90 per cent, were used as representative of the probable range of relative humidities. The dry-bulb temperature was altered within the range 20 C-35 C (68.0 F-95.0 F).

In room B an atmosphere of still air, with a relative humidity varying between 80 and 90 per cent and a dry-bulb temperature range of 20 C-30 C (68.0 F-86.0 F) was used. This high relative humidity was used first to insure the greatest degree of accuracy, since the error in the estimation of effective temperature is least when the atmospheric conditions are represented on the Mollier diagram by a point as close as possible to the 100 per cent relative humidity line from which the effective temperature is read; and secondly, because it is considered impossible to produce comfortable conditions when the relative humidity rises above 90 per cent.

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[1] J. A. Wiesebron: 1940 Psychrometrisch Onderzoek Aangande het Behaaglijkheidsgebeid in Nederlandsch—Indie.

[2] The Application of the Effective Temperature Scheme to the Comfort Zone in Netherlands India, by J. A. Wiesebron, C. P. Mom, R. Courtice and C. J. Kip. (ASHVE Journal Section, Heating, Piping & Air Conditioning, October, 1942, pp. 622-640.)

[3] Loc. Cit. See Note 1.

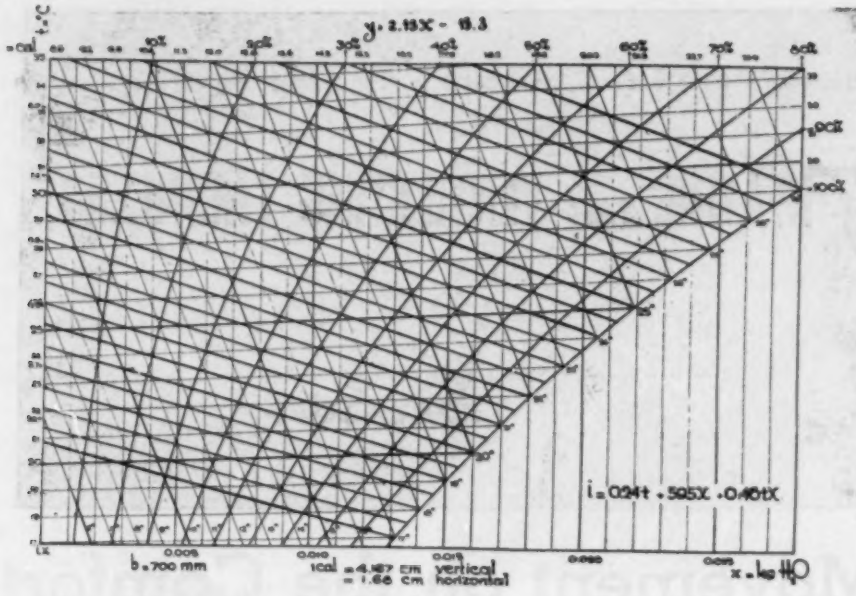

Fig. 1—Lines of effective temperature superimposed on Mollier diagram†

An observer sat in each room and recorded dry-bulb temperature, wet-bulb temperature (using an electrical psychrometer, which gave a uniform air velocity on the surface of the thermometer bulbs), and comparative feeling of comfort of the normally clothed subject. Frequent checks were made upon the air velocity by means of kata thermometer readings.

Comparison of Still and Turbulent Atmospheres

The subject passed frequently from one room to the other and expressed his comparative feeling of comfort in the two rooms. Atmospheric conditions could be readily adjusted in either room. In room A six separate sets of turbulent atmospheric conditions were used, the air velocity and relative humidity being constant for each set of conditions with the dry-bulb temperature varying over the range 20 C-35 C (68.0 F-95.0 F). Air velocities of 60 and 120 cm/sec (118 and 236 fpm, respectively) with relative humidities of 45, 60 and 90 per cent were used in room A. Approximately 30 equal readings were obtained for each subject.

Results

For each subject the dry-bulb temperature in room A was plotted graphically against the corresponding effective temperature in room B, calculated from the effective temperature chart (Fig. 1). This procedure was adopted for each of the six sets of atmospheric conditions produced in room A. It was found that there was a linear relationship between the dry-bulb temperature and effective temperature corresponding to each set of atmos-

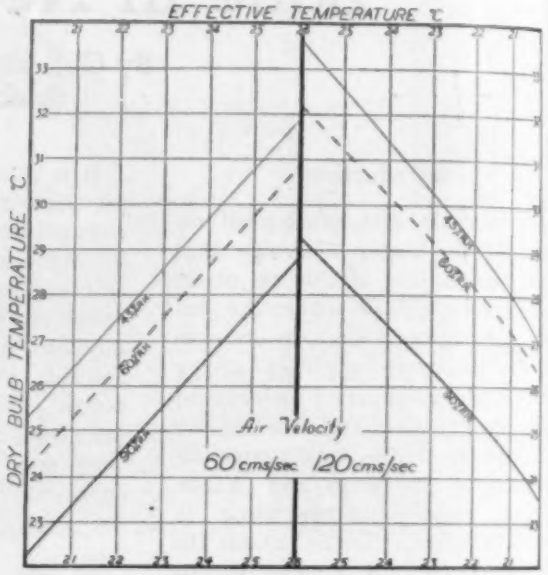

Fig. 2—Graph correlation effective temperature, dry bulb temperature, relative humidity (45, 60 and 90 per cent) and air velocities of 60 cm per second (118 fpm) and 120 cm per second (236 fpm)

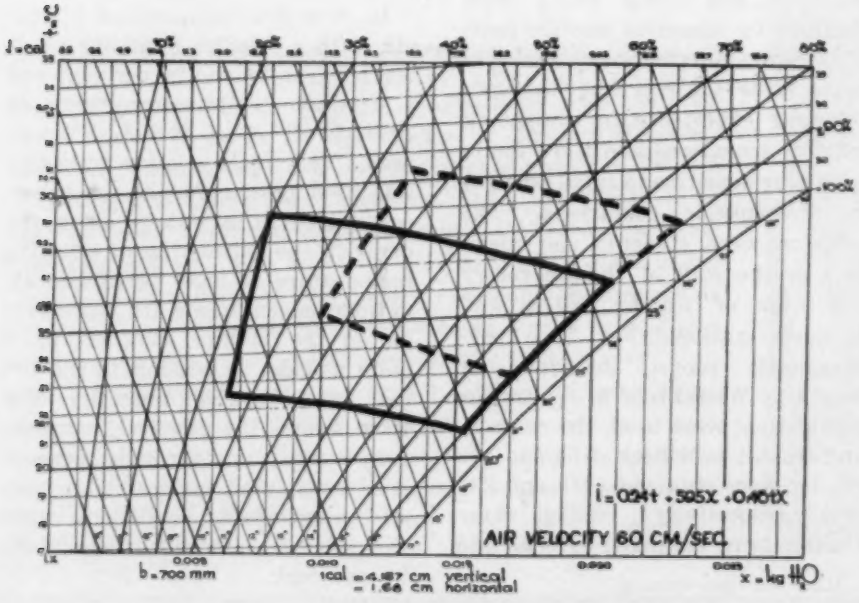

Fig. 3—Shifting of comfort zone in the range of relative humidity 45 per cent-90 per cent when an air velocity of 60 cm per second (118 fpm) is added to still air

†Loc. Cit. See note 2.

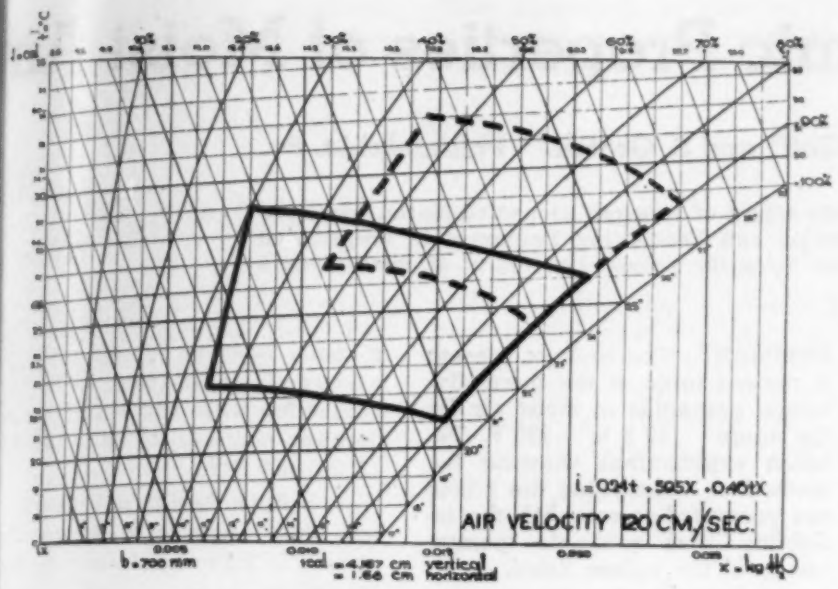

Fig. 4—Shifting of comfort zone in the range of relative humidity 45 per cent-90 per cent when an air velocity of 120 cm per second (236 fpm) is added to still air

pheric conditions, *e.g.*, 120 cm/sec air velocity (118 fpm) and 60 per cent relative humidity. *Lines of best fit* were calculated and drawn and next the average line of best fit for each of the six sets of atmospheric conditions previously described was obtained. These lines are depicted in Fig. 2. As an example it will be seen that with a relative humidity of 60 per cent and air velocity of 120 cm/sec (118 fpm), a dry-bulb temperature of 31 C (87.8 F) is equivalent to an effective temperature of 24.8 C (76.7 F). A dry-bulb temperature of 31 C (87.8 F) with a relative humidity of 60 per cent, *and still air* is equivalent to an effective temperature of 27.8 C (82.0 F)—Fig. 1.

Finally, a Mollier diagram with a superimposed comfort zone for still air was taken and the shift of this zone produced by air velocities of 60 cm/sec (118 fpm) and 120 cm/sec (236 fpm) determined for the range of relative humidity 45-90 per cent.

This shifting of the comfort zone was determined in the following way. Three points on the lower border of the comfort zone are 45 per cent relative humidity and dry-bulb temperature 22.2 C (72.0 F), 60 per cent relative humidity and dry-bulb temperature 22 C (71.6 F), 90 per cent relative humidity and 21 C (69.8 F). The effective temperature for each of these points can be determined by reference to Fig. 1, *e.g.*, 21 C (69.8 F) dry-bulb temperature and 90 per cent relative humidity is equivalent to an effective temperature of 20.6 C (69.1 F). By reference to Fig. 2 an effective temperature of 20.6 C (69.1 F) is equivalent to a dry-bulb temperature of 22.8 C (73.0 F) and 90 per cent relative humidity with an air velocity of 60 cm/sec (118 fpm). Similar points are obtained for relative humidities of 45 and 60 per cent.

The upper border of the comfort zone is shifted in a similar manner.

In Figs. 3 and 4 the effects of the addition of air velocities of 60 cm/sec (118 fpm) and 120 cm/sec (236 fpm) upon the location of the comfort zone are shown. The boundaries of the comfort zone for still air are represented by a continuous line, those for moving air by an interrupted line.

Conclusion

The effects of air movement upon the comfort zone in Netherlands India were determined. The air velocities used, namely, 60 cm/sec (118 fpm) and 120 cm/sec (236 fpm), can be produced readily in offices, bedrooms, theaters and similar indoor spaces by means of electric fans, suitably arranged. By the addition of this air movement to a still atmosphere, the atmospheric conditions may be transferred from the heat accumulation zone to the comfort zone.

Acknowledgment

This work was interrupted by the Japanese invasion of the Far East in 1942 so that it was not finished. It was carried out by the authors in collaboration with and under the supervision of C. P. Mom[4] and J. A. Wiesebron.[5]

This paper has been prepared for publication in order to put on record the work of those who so unfortunately have been taken prisoner by the enemy.

The authors wish to thank Prof. D. H. K. Lee of the Queensland University for his advice in the preparation of this paper.

The diagrams were drawn and photographed by A. M. Tuffley of the Physiology Department at the Queensland University.

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[5]Physical Assistant at the Technical Hygiene Laboratory, Bandoeng, Java.

YORK ANNOUNCES NEW DIVISION MANAGER

York-Shipley, Inc., York, Pa., announces the appointment of E. P. Fahey as division manager. Mr. Fahey has a varied and successful background of experience in the heating and plumbing industries, and was a pioneer in the oil burning field, starting with the installation of oil burners in Kansas in 1911. He was formerly president of Ray Heat Power Co., Chicago, and Eastern manager for the Ray Oil Burner Co., San Francisco. More recently he has served as an engineering consultant for R. H. Monsell Co. and Energy Control Co., both of New York, and Smukler Plumbing Supply Co., Morristown, N. J.

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Thermodynamic Properties of Moist Air

By John A. Goff* and S. Gratch,** Philadelphia, Pa.

This paper is the report of research sponsored by the American Society of Heating and Ventilating Engineers in cooperation with the Towne Scientific School, University of Pennsylvania

SUMMARY—The authors present a revised table of the thermodynamic properties of moist air for the range —160 F to +200 F. Detailed explanations showing the method of constructing the tables are presented to establish the reliability and probable permanence of the values listed.

Introduction

The ultimate objective of this cooperative investigation has been a formulation of the thermodynamic properties of moist air which, on account of accuracy and thermodynamic consistency, could claim universal acceptance as standard.

The results of the investigation are presented in Table 4, Thermodynamic Properties of Moist Air (which is intended as a revision of the present 1944 and 1945, Heating, Ventilating, Air Conditioning Guide, Chapter 1, Table 6) and in the accompanying detailed explanation of the method used in constructing Table 4. The explanation as presented should offer a means of judging the reliability and probable permanence of the data.

It is hoped that the methods employed in constructing the tables will be helpful and instructive to those who have occasion to deal with the general problem of gas mixtures.

I. Dry Air

Composition. For the purpose of analysis, moist air can be regarded as a mixture of only two constituents, dry air and water vapor. This is so because the composition of dry air is practically constant both as to time and location, the only detectable variation being in the carbon dioxide (CO_2) content. According to *International Critical Tables*,[1] the mol-fraction composition of dry air is that given in Table 1. All monatomic gases except argon (A) are present in traces only; hence, in computing their contributions to apparent molecular weight, enthalpy, and entropy, no appreciable error is committed by lumping them together as argon.

Table 1 also lists the molecular weights used in the present analysis. Those for CO_2 and H_2 are from *International Critical Tables*,[2] those for N_2 and A are from Cragoe,[3] that for O_2 is a matter of definition. With these individual molecular weights the apparent molecular weight of the mixture, dry air, is readily computed.

Specific Volume. At all accessible temperatures, say above 0.001 °R, the zero-pressure value of the pressure-volume product pv ($ft\ lb/mol$) is strictly proportional to absolute temperature T (° R), the constant of proportionality being the universal gas constant R ($ft\ lb/mol$ ° R). According to Cragoe,[3] the best value of the product RT_o, where T_o denotes ice-point temperature, is 22414.6 (atm cm³/g mol). Beattie[4] recommends the value $T_o = 273.165 \pm 0.015$ °K. Combining these and converting to English units yield $R = 1545.31$ (ft lb/mol °R).

At sufficiently low, but nevertheless finite pressure p, the specific volume is given accurately by the expression,

$$pv = RT - A_{aa}(T) \cdot p - A_{aaa}(T) \cdot p^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.0$$

where the temperature functions $A_{aa}(T)$ and $A_{aaa}(T)$ are called second and third virial coefficients, respectively. The letter a refers specifically to dry air; the meanings of the double and triple subscripts will be explained later.

Numerical values of second and third virial coefficients are derivable from Bridgeman's[5] adjustment of the constants in the well-known Beattie - Bridgeman equation of state[6] to fit the experimental data of Holborn and Schultze,[6] namely,

$$\left.\begin{array}{l} R = 0.08206 \\ T_o = 273.13 \\ A_o = 1.0763 \\ B_o = 0.04070 \\ a = 0.01697 \\ b = -0.02174 \\ c = 12 \times 10^4 \end{array}\right\} \quad \ldots\ldots\ldots 2.1$$

The units of these constants are such that each term in the following equations obtained from rearrangement of the Beattie-Bridgeman equation is dimensionless if

Table 1—Composition of Dry Air

Gas	Mol-fraction	Molecular Weight	lb/mol dry air
Nitrogen (N_2)	0.7803	28.0149	21.8600
Oxygen (O_2)	0.2099	32.0000	6.7168
Carbon Dioxide (CO_2)	0.0003	44.003	0.0132
Hydrogen (H_2)	0.0001	2.016	0.0002
Monatomic Gases	0.0094	39.943	0.3755
Apparent Molecular Weight (lb/mol)			28.966

Composition of Monatomic Gases	
Argon (A)	0.00933
Neon (Ne)	0.000018
Helium (He)	0.000005
Krypton (Kr)	0.000001
Xenon (Xe)	0.
	0.00935

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[1]Exponents refer to References at end of paper.

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pressure is expressed in atmospheres and temperature in degrees Kelvin.

$$\frac{A_{aa}p}{RT_o} = -B_o p/RT_o + \frac{A_o p/R^2T_o}{T} + \frac{cp/RT_o}{T^3} \quad \text{.....2.2}$$

$$\left.\begin{aligned} a_2 &= 53.6 \times 10^{-60} \text{ (erg cm}^6\text{)} \\ a_4 &= 114.9 \times 10^{-76} \text{ (erg cm}^8\text{)} \\ a_5 &= 127.9 \times 10^{-92} \text{ (erg cm}^{10}\text{)} \end{aligned}\right\} 2.7$$

$$\frac{A_{aaa}p^2}{RT_o} = \frac{B_o(B_o+b)p^2/RT_o}{T} - \frac{A_o(2B_o+a)p^2/R^2T_o}{T^2} + \frac{A_o^2p^2/R^4T_o}{T^3} - \frac{cB_op^2/R^2T_o}{T^4} + \frac{2cA_op^2/R^3T_o}{T^5} + \frac{c^2p^2/R^4T_o}{T^7} \quad \text{.....2.3}$$

After inserting Bridgeman's values of the constants, the following data are easily computed for a pressure of 1 atmosphere:

t (F)	176	−160
RT/RT	1.000000	1.000000
$-A_{aa}p/RT$	0.000029	−0.004691
$-A_{aaa}p^2/RT$	0.000003	−0.000012
pv/RT	1.000032	0.995297

These calculations show that, at both extremes of the temperature range of present interest, the contribution to the specific volume from the third virial coefficient A_{aaa} is less than the probable uncertainty in the contribution from the second virial coefficient A_{aa}, at any rate at atmospheric pressure.

Converting (2.2) to English units with temperature expressed in degrees, Rankine gives

$$A_{aa}(T) = -0.6520 + \frac{378.18}{T} + \frac{11.2 \times 10^6}{T^3} \text{ (ft}^3\text{/mol)} \quad \text{.....2.4}$$

This equation is purely empirical and involves adjustment of three constants. Goff, Andersen and Gratch[7] have shown that fair agreement with (2.4) is obtained by the adjustment of only one constant in a semi-theoretical expression for the force potential $E(r)$ appearing in the statistical mechanical expression for the second virial coefficient of a non-polar gas, namely,

$$A(T) = 2\pi N_o \int_o^\infty \left(e^{-\frac{E(r)}{kT}} - 1\right) r^2 dr \quad \text{....2.5}$$

N_o = Avogadro's number
k = Boltzmann's constant
r = distance between members of a pair of molecules.

The forces contributing to the potential E are of two sorts, long-range attractive forces and short-range repulsive forces. In the case of a non-polar gas, the only long-range attractive forces are the so-called *dispersion forces* arising from momentary deformation of the electron clouds surrounding the atoms which, in an aggregate of molecules, produces a tendency toward alignment into attractive orientations. The contribution to the potential E from such forces is a negative one depending only on distance of separation r and being of the form

$$E_-(r) = -(a_3r^{-6} + a_4r^{-8} + a_5r^{-10}) \quad \text{.....2.6}$$

The coefficients a_3, a_4, a_5 are derivable from optical dispersion data.

As previously noted, dry air is not a pure gas so that (2.5) is not strictly applicable to it. However, all of its constituents except carbon dioxide (CO_2), which is present in small concentration only, are non-polar; and its two principal constituents, oxygen (O_2) and nitrogen (N_2), show roughly the same values of the coefficients a_3, a_4, a_5. Therefore, it ought to be a good approximation to the truth to regard dry air as a pure gas, assigning to it dispersion force coefficients obtained by averaging those of its principal constituents weighted in proportion to their mol fractions in the mixture. The values thus obtained for dry air from data by Margenau[7,8] are:

At very short distances of separation the force between a pair of molecules becomes repulsive, the potential E becoming positively infinite as r decreases toward zero. As a first approximation, therefore, it may be assumed that $E(r) = \infty$ for $r < r_o$. It is also known that the repulsive forces are negligibly small except at very short distances of separation; hence it may be assumed further that $E(r) = E_-(r)$ for $r > r_o$. These assumptions give a force potential $E(r)$ characteristic of the so-called "rigid sphere" molecule which has been used successfully in several cases.[9] With it the integral in (2.5) is relatively easy to evaluate. In the preliminary analyses referred to above,[7] the value $r_o = 3.396 \times 10^{-8}$ cm was found to bring (2.5) into fair agreement with (2.4) within a limited temperature range as shown by curves A and B, Fig. 1.

From the above comparison it is clear that the *rigid sphere* model is hardly adequate for the purpose at hand. A better method of treating the repulsive forces is to assume their contribution to $E(r)$ except at extremely short distances of

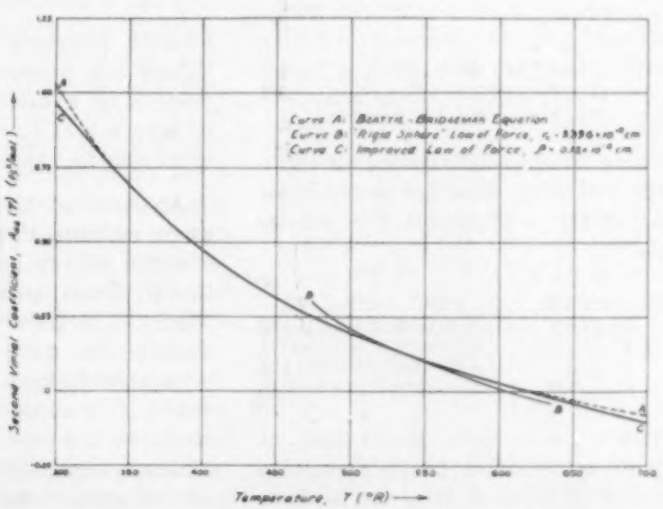
Curve A: Beattie-Bridgeman Equation
Curve B: "Rigid Sphere" Law of Force, $r_o = 3.396 \times 10^{-8}$ cm
Curve C: Improved Law of Force, $\beta = 0.82 \times 10^{-8}$ cm
Second Virial Coefficient, $A_{aa}(T)$ (cu ft/lbmol) ⟶
Temperature, T (°R) ⟶

Fig. 1—Second virial coefficient for dry air

separation (say $r < 0.5 \times 10^{-8}$ cm) to be of the form $Pe^{-r/\rho}$, *where* P and ρ are constants. This form with $\rho = 0.28 \times 10^{-8}$ cm is known to be appropriate for some of the simplest molecules[10,11] and, as will be shown, it enables (2.5) to give satisfactory agreement with (2.4) in the case of dry air. The improved law of force becomes

$$E(r) = \infty \text{ for } r < 0.5 \times 10^{-8} \text{ cm} \quad \ldots 2.8$$
$$E(r) = Pe^{-r/\rho} - (a_6 r^{-6} + a_8 r^{-8} + a_{10} r^{-10})$$
for r greater than or equal to 0.5×10^{-8} cm

It would appear from (2.8) that there are now two constants to be adjusted, but it turns out that ρ may be assigned *a priori* any value in the range 0.10×10^{-8} to 0.30×10^{-8} cm and the effect of such assignment almost completely compensated, except at very high temperatures, by subsequent adjustment of P. The values $\rho = 0.12 \times 10^{-8}$ cm, $P = 5.056 \times 10^{-2}$ erg give curve C of Fig. 1. The corresponding force potential $E(r)$ is sketched in Fig. 2, which also shows a dotted line representing the *rigid sphere* potential used in calculating curve B of Fig. 1. It is not contended that these values represent the best possible adjustment, but merely that they prove the adequacy of the theory which will be put to important use later.

Enthalpy and Entropy. Expressions for specific enthalpy and specific entropy are derivable from (2.0) by application of appropriate identical relations of thermodynamics. The results are:

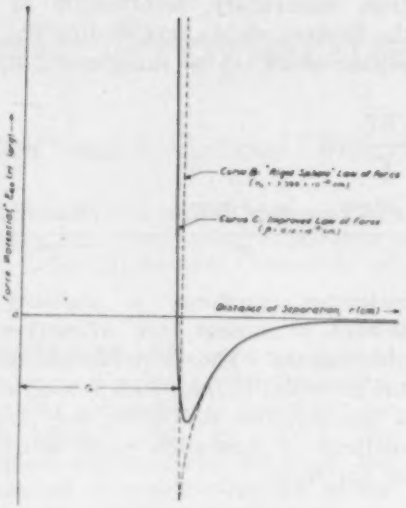

Fig. 2—Laws of force for dry air

$$h_a = h_a^\circ(T) - B_{aa}(T)\,p - \tfrac{1}{2} B_{aaa}(T)\,p^2 \quad \ldots 3.0$$

$$s_a + R \log_e p = s_a^\circ(T) + C_{aa}(T)p + \tfrac{1}{2} C_{aaa}(T)p^2 \quad \ldots 3.1$$

where

$$B = d(A\tau)/d\tau \quad \ldots 3.2$$
$$C = dA/dT \quad \ldots 3.3$$
τ = reciprocal temperature

Using Bridgeman's constants (2.1) the following data are easily computed for a pressure of 1 atmosphere

t (°F)	176	−160
$B_{aa}p/RT$	+0.001535	+0.016165
$\frac{1}{2} B_{aaa}p^2/RT$	−0.000003	+0.000071
$C_{aa}p/R$	−0.001564	−0.011475
$\frac{1}{2} C_{aaa}p^2/R$	+0.000001	−0.000065

These calculations show that, at both extremes of the temperature range of interest, the contributions to specific enthalpy and specific entropy from the third virial coefficient A_{aaa} are less than the probable uncertainties in the corresponding contributions from the second virial coefficient A_{aa}, at any rate at atmospheric pressure. Consequently, in subsequent calculations at pressures not greatly exceeding atmospheric, the third virial coefficient A_{aaa} will be completely ignored.

From (3.0) it is clear that $h_a^\circ(T)$ is the zero-pressure enthalpy. Until recent developments in the science of interpreting band spectra made it possible to calculate $h_a^\circ(T)$ from spectroscopic data, the only method of evaluating it was to extrapolate to zero pressure experimental measurements of h_a made at accessible pressures. At present, however, the calculated values are generally regarded as possessing a much higher degree of accuracy and reliability than the extrapolated values.

Analysis of the spectrum of a given molecule determines a set of discrete energy levels ϵ_i ($i = 0, 1, 2, —$). From quantum mechanical theory it is known that it is often possible for more than one accessible state to have the same energy level ϵ_i; hence it is also necessary to know the statistical weight p_i of each level, that is, the number of accessible states having that level. Given this information, it is a straightforward, though sometimes quite complicated, task to compute the so-called state sum defined as follows:

$$Q = \sum_{i=0}^{\infty} p_i e^{-\frac{\epsilon_i}{kT}} \quad \ldots 3.4$$

But statistical mechanics predicts that the zero-pressure enthalpy is derivable from the state sum Q as follows:

$$\frac{h^\circ - \bar{u}}{RT} = T\left[\frac{\partial \log_e (QT)}{\partial T}\right]_v \quad \ldots 3.5$$

The constant $\bar{u}$ is the internal energy at zero temperature and zero pressure and is called the null-point energy. Because of the fact that, even at absolute zero ($T = 0$), there persists appreciable translational kinetic energy in a gas, there is a finite difference between null-point energy and null-point enthalpy. However, this difference is extremely small except in the case of an electron gas and can therefore be ignored in the present analysis. In problems not involving chemical changes the null-point energy can arbitrarily be assigned any convenient value.

Dry air is a mixture of several gases, but statistical mechanics predicts that the zero-pressure enthalpy of such a mixture is the sum of separate contributions from its several constituents; thus

$$h_a^\circ = \Sigma\, x_i(h_i^\circ - \bar{u}_i) + \Sigma\, x_i \bar{u}_i \quad \ldots 3.6$$

where x denotes mol fraction. In constructing Table 6, the constant $\Sigma\, x_i \bar{u}_i$ has been adjusted to make the specific enthalpy h_a zero at 0F and standard atmospheric pressure.

For nitrogen (N_2) we have computed the state sum Q using the same spectroscopic data employed by Johnston and Davis.[12] These data do not include values of the energy levels ϵ_i (erg) but rather those of wave numbers ν_i (cm^{-1}). These are related in a simple manner, namely, $\epsilon_i = hc\nu_i$, *where* h denotes Planck's constant (erg sec) and c the velocity of light *in vacuo* (cm/sec). In the state sum Q the various physical constants appear

only in the combination hc/k (cm °K), and for this combination the value 1.4324 was used. Even though more accurate spectroscopic data and more accurate values of the physical constants than those employed by Johnston and Davis may now be available, it did not seem necessary to search them out, because, in the temperature range of interest, the corrections determined by them would certainly be entirely negligible.

For oxygen (O_2) the state sum calculations of Johnston and Walker[13] were used directly, semi-theoretical equations being employed in the necessary interpolation to the temperatures listed in Table 4. Since the mol fraction of oxygen in dry air is only about 21 per cent, inaccuracies in the Johnston and Walker values are not reflected into the final results.

For the remaining constituents of dry air (Table 1) values in the literature[14] were accepted without question since the concentrations are sufficiently small to submerge any possible inaccuracies.

From (3.1) it is clear that $s_a°(T)$ is the zero-pressure value of the sum, $s_a + R \log_e p$, which may be called *reduced entropy*. The zero-pressure reduced entropy of a pure gas is derivable from the state sum Q as follows:

$$\frac{s° - \bar{s}}{R} = \frac{h° - \bar{u}}{RT} + \log_e\left(\frac{QRT}{e\,v}\right) \quad .3.7$$

Actually Q is proportional to specific volume v, the ratio Q/v being dimensionless. This makes $s°/R$ a pure temperature function as required by (3.1). In computing the logarithm in (3.7) the unit of R must be so chosen that the quantity RT/v has the unit desired for pressure.

The zero-pressure reduced entropies of the several constituents of dry air were obtained from the same sources as were the zero-pressure enthalpies. For the mixture, namely, dry air, statistical mechanics predicts that

$$s_a° = \Sigma\, x_i(s_i° - \bar{s}_i) - R\,\Sigma\, x_i \log_e x_i + \Sigma\, x_i\bar{s}_i \quad \ldots\ldots\ldots\ldots\ldots\ldots .3.8$$

Although statistical mechanics further predicts (Third Law of Thermodynamics) that, even when chemical changes are contemplated, each of the constants $\bar{s}_i$ may be assigned the value zero, this procedure has not been followed. Instead the constant $\Sigma\, x_i\bar{s}_i$ has been adjusted to make the specific entropy s_a zero at 0 F and standard atmospheric pressure.

Summary. The values of specific volume of dry air v_a listed in the proposed revision of Table 6 have been computed from (2.0), using $R = 1545.31$ (ft lb/mol °R) and $M = 28.966$ (lb/mol), obtaining A_{aa} from (2.2) after inserting the Bridgeman constants (2.1), and ignoring the third virial coefficient A_{aaa}. The values of specific enthalpy h_a have been computed from (3.0), obtaining B_{aa} from (2.2) through (3.2), ignoring the third virial coefficient B_{aaa}, constructing $h_a°$ in accordance with (3.6) from individual zero-pressure enthalpies computed from spectroscopic data with $R = 1.9858$ Btu/mol °R and from the mol fractions listed in Table 1, adjusting the constant $\Sigma\, x_i\bar{u}_i$ to make $h_a = 0$ at 0 F and standard atmospheric pressure. The values of specific entropy s_a have been computed from (3.1), obtaining C_{aa} from (2.2) through (3.3), ignoring C_{aaa}, constructing $s_a°$ in accordance with (3.8) from individual zero-pressure reduced entropies computed from spectroscopic data, adjusting the constant $\Sigma\, x_i\bar{s}_i$ to make $s_a = 0$ at 0 F and standard atmospheric pressure.

II. Water

Introduction. Since publication in 1936 of the Keenan-Keyes steam tables,[15] new experiments and theoretical developments have indicated that the data included are inaccurate at low pressures and temperatures. The *Bureau of Standards* calorimetric measurements[16] published in 1939 indicate an error of about 0.7 Btu/lb in the steam table value of the enthalpy of saturated steam at 32 F. Measurements of isothermal Joule-Thomson coefficient B_{ww} reported by Collins and Keyes[17] in 1938 show that the values of this coefficient used in formulating the steam tables are in error by about 15 per cent in the range 40 to 60 C, and by about 10 per cent at 80 C. Recalculation of the zero-pressure properties by Stephenson and McMahon[18] from the newer spectroscopic data of Randall, Dennison, Ginsberg, and Weber[19] indicate an error of as much as 0.4 Btu/lb in zero-pressure enthalpy in the range 0 to 100 C. The steam table values of vapor pressure in this range are not as accurate as desired, the tolerance of 0.05 per cent at 80 C set by the Third Steam Table Conference[20] in 1935 producing an uncertainty of 0.1 per cent in the humidity ratio of saturated moist air at atmospheric pressure and a corresponding uncertainty of 0.5 Btu/lb dry air in its enthalpy. If the thermodynamic properties of moist air were to be computed from present steam table data, the overall uncertainty would be too large to warrant their acceptance as standard; for example, the overall uncertainty in the enthalpy of saturated moist air would probably exceed 1 Btu/lb of dry air.

If the above mentioned uncertainties in the properties of water could only be reduced by additional experimentation, which would necessarily have to be quite elaborate, the end might not justify the means. Fortunately, however, a considerable reduction can be accomplished by correlation of the newer data already available. We have attempted such correlation and shall describe it briefly here with the intention of publishing a full account later. For the sake of completeness the properties of condensed water (liquid and solid phases) are included.

Condensed Water. It is universal practice in steam table work to select saturated liquid at 32 F as reference point, assigning the value zero to both enthalpy and entropy at that point. This practice has been adhered to in constructing Table 4. Osborne[21] has recalculated earlier data on the latent heat of fusion at 32 F and atmospheric pressure and has recommended the value 333.48 ± 0.2 int joule/gram. To correct this figure to saturation pressure, the identical relation of thermodynamics, namely,

$$\left(\frac{\partial h}{\partial p}\right)_T = \left[\frac{\partial(vT)}{\partial T}\right]_p \quad \ldots\ldots .6.1$$

may be used, evaluating the right hand member (1) for ice from data on thermal coefficient of expansion by Jakob and Erk[22] and the value of specific volume at 32 F given by Keenan and Keyes[15] and (2) for liquid from the data of Osborne, Stimson and Ginnings.[16] The correction to the enthalpy turns out to be only 0.001 Btu/lb and therefore negligible. Accordingly the enthalpy and entropy of ice at 32 F and saturation pressure are —143.40 Btu/lb and —0.29164 Btu/lb °F, respectively. Values of the enthalpy and entropy of ice at lower temperatures can now be obtained from the calorimetric measurements of Giauque and Stout[23] after correction from atmospheric to saturation pressure and conversion to the steam table Btu.

For the properties of liquid water at saturation pressure and above 32 F, the *Bureau of Standards*[16] values are used directly.

Zero-pressure Properties of Water Vapor. Gordon[24] has calculated the zero-pressure properties of water vapor from the spectroscopic data of Mecke, et al.[25] Wilson[26] has subsequently estimated a correction to the Gordon values to account for the centrifugal distortion of the water molecule, the so-called *stretching effect.* Stephenson and McMahon[18] have evaluated this effect more accurately from the newer spectroscopic data of Randall, Dennison, Ginsberg, and Weber.[19] We have found that the best information presently available is adequately† represented, in the range 100 to 1000 K by the following semi-theoretical formulae:

$$\frac{h^\circ - \bar{u}}{T} = 0.440912 + 0.110228 \sum_{i=1}^{3} \left(\frac{\theta_i \tau}{e^{\theta_i \tau} - 1} + a_i\, \theta_i\, \tau\, e^{-\theta_i \tau} \right) + 1.427 \times 10^{-6}\, T - \frac{0.9943}{T} \text{ (Btu/lb °R)} \quad \ldots\ldots 7.1$$

$$s^\circ - s = 0.440912 \log_e T + 0.110228 \sum_{i=1}^{3} \left[\frac{\theta_i \tau}{e^{\theta_i \tau} - 1} + \log_e \left(\frac{e^{\theta_i \tau}}{e^{\theta_i \tau} - 1} \right) + a_i (1 + \theta_i \tau)\, e^{\theta_i \tau} \right] + 2.854 \times 10^{-6}\, T - 0.26958 \text{ (Btu/lb°R)} \quad \ldots\ldots 7.2$$

In these formulae the *characteristic temperatures* θ_i and the coefficients a_i have been obtained by least squares adjustment to best fit the data described above; temperature is to be expressed in degrees Rankine (°R); the unit chosen for pressure in $s^\circ = (s + R \log_e p)_{p=0}$ is the standard atmosphere; and the molecular weight of water is 18.0154 lb/mol. The numerical values of the constants are:

$$\begin{aligned} \theta_1 &= 4124.09\ ^\circ\text{R} & a_1 &= -0.03958 \\ \theta_2 &= 9317.47\ ^\circ\text{R} & a_2 &= \ \ 0.05353 \\ \theta_3 &= 9802.06\ ^\circ\text{R} & a_3 &= \ \ 0.04000 \end{aligned}$$

The null-point constants $\bar{u}$ and $\bar{s}$ remain to be fixed in such a way that the enthalpy and entropy of saturated liquid at 32 F will both be zero in accordance with steam table practice.

Virial Coefficients. Empirical formulae for second and third virial coefficients are derivable from the formulation of Keyes, Smith and Gerry[27] based on their own measurements of specific volume at temperatures in the range 195 to 460 C. These are:

$$A_{ww} = -1.89 + 2641.62\, \tau \cdot 10^{3670\tau^2} \text{ (cm}^3\text{/g)} \quad \ldots\ldots 8.1$$

$$A_{www} = (A_{ww}\tau)^3\ (-82.546 + 1.6246 \times 10^5 \tau) \text{ (cm}^3\text{/g atm)} \quad \ldots\ldots 8.2$$

where temperature is in degrees Kelvin (°K).

These formulae have been used for the necessary extrapolation to lower temperatures in constructing the Keenan-Keyes tables.[15] Subsequently, Collins and Keyes[17] found that values of B_{ww} derived from (8.1) are in error by about 15 per cent at 40 C and about 3 per cent at 125 C. They also found that values of B_{www} derived from (8.2) are in error by about 20 per cent at 80 C and about 15 per cent at 125 C.

The Collins and Keyes[17] data cover the range 40 to 125 C only and are not sufficiently accurate or extensive to stand extrapolation to the lower temperatures in Table 6. Furthermore, their measurements were made directly on B_{ww} and B_{www} so that only the temperature dependence, not the absolute values, of A_{ww} and A_{www} are derivable therefrom. The Keyes, Smith, Gerry[27] formulation (8.1), (8.2) cannot be expected to yield reliable values of these constants of integration since extrapolation from 195 to 125 C would be required. Fortunately, however, the new *Bureau of Standards*[16] calorimetric measurements furnish a way out of the dilemma.

The *Bureau of Standards*[16] data include values of saturation enthalpy h_g of high precision and may be used to evaluate the left hand side of

$$B_{ww}\, p_s + \tfrac{1}{2}\, B_{www} p_s^2 = (h^\circ - \bar{u})_w - h_g + \bar{u}_w \quad \ldots\ldots 8.3$$

to within a constant quantity $\bar{u}_w$. This can be fixed by comparison with the values given by Collins and Keyes[17] for B_{ww} at 38.94, 59.44, 80.02, 100, and 125 C and for B_{www} at 80.02, 100, and 125 C, using existing vapor pressure data p_s which are sufficiently accurate for the purpose. The value thus obtained is 859.114 Btu/lb with an average deviation of only 0.01 Btu/lb which may be taken to indicate a high degree of consistency in the various data used. The necessary extrapolation of B_{www} to temperatures below 80 C to enable all values of B_{ww} to be used in fixing $\bar{u}_w$ can hardly introduce appreciable uncertainty into the adjustment of $\bar{u}_w$ because the term $\frac{1}{2}\, B_{www}\, p_s^2$ decreases so rapidly with decreasing temperature and amounts to less than 0.1 Btu/lb at 59.44 C.

Having fixed the constant $\bar{u}_w$ in the above manner values of the sum, $B_{ww}\, p_s + \frac{1}{2}\, B_{www}\, p_s^2$, were computed from (8.3) over the range 0 to 125 C; then values of

†For the range 298.1 to 1500°K: root mean square deviation = 0.00003 for (7.1), 0.00002 for (7.2); mean algebraic deviation = +0.000006 for (7.1), —0.000002 for (7.2).

$\frac{1}{2} B_{www} p_s^2$ computed from the data of Collins and Keyes[17] and suitably extrapolated to *OC* were subtracted to obtain values of $B_{ww} p_s$. These were divided by existing values of vapor pressure p_s and the resulting values of B_{ww}, together with the direct measurements of Collins and Keyes,[17] were then formulated into the empirical equation (8.5). Finally, the values of $\frac{1}{2} B_{www} p_s^2$ used in the above reduction were divided by $\frac{1}{2} p_s^2$ to obtain corresponding values of B_{www} which in turn were formulated (somewhat arbitrarily, since only three values were available for the purpose) into the empirical equation (8.8). Using the identical relations (3.2) and (3.3), the remaining temperature coefficients are readily obtained, the complete list being

$$A_{ww}\tau = -0.0304\,\tau + 90.432\tau^3 e^{\frac{25020}{T}^8} + C_o \quad \ldots\ldots 8.4$$

$$B_{ww}\tau = -0.0304\tau + (A_{ww}\tau + 0.0304\tau - C_o)\ (2 + 1{,}060{,}640\tau^3) \quad \ldots\ldots 8.5$$

$$C_{ww} = A_{ww}\tau - B_{ww}\tau \quad \ldots\ldots 8.6$$

$$A_{www}\tau = 66.1\ (A_{ww}\tau - C_o)^3 + C_1 \quad 8.7$$

$$B_{www}\tau = 198.3\ (A_{ww}\tau - C_o)^2\ B_{ww}\tau \quad \ldots\ldots 8.8$$

$$C_{www} = A_{www}\tau - B_{www}\tau \quad \ldots\ldots 8.9$$

where the first three are given in ft³/lb °R and the last three in ft⁵/lb² °R.

To fix the constants of integration C_o and C_1 values of pv at saturation for temperatures above 95 C, where sufficiently reliable values of vapor pressure and its temperature derivative are obtainable from the formula of Osborne and Meyers,[28] were computed from the identical relation,

$$(pv)_s = \gamma \frac{d\log_e T}{d\log_e p_s} \quad \ldots\ldots 8.10$$

where γ is a calorimetric quantity directly measured at the *Bureau of Standards*,[16] and compared with values computed for the same temperatures from

$$(pv)_s = RT - A_{ww}p_s - A_{www}p_s^2 \quad \ldots\ldots 8.11$$

It was found in this manner that both C_o and C_1 were zero within the accuracy of the data used.

The above empirical formulae may be regarded as valid from 0 to 125 C. They do not merge smoothly with the Keyes, Smith and Gerry[27] formulation valid above 195 C, but this is not considered a serious defect so long as they are not to be used above 100 C.

In the previous section on dry air, considerable discussion of the application of modern theory regarding intermolecular forces to predict values of second virial coefficient was given. In the case of water vapor, the problem is much more complex due to the polar character of the water molecule which makes the potential E depend upon mutual orientation as well as on distance of separation. We have found that the constants P and ρ together with certain fictitious constants expressing the effects of dipole alignment and induction can be adjusted to fit existing data on B_{ww} although such adjustment does not yield unique values of A_{ww} as was originally hoped. It is interesting to note, however, that the adjusted value of ρ was near 0.24 $\times 10^{-8}$ cm. More recently Margenau and Myers[29] have refined the theory to take proper account of the polar character of the water molecule and have obtained fair agreement with data on A_{ww}.

Table 2—Values of f(t)

t (deg F)	$10^7 f(t)$	$10^5 \int_{212}^{t} f(t)\,dt$
32	—2	46
50	—4	40
68	—6	32
86	—6	21
104	—6	11
122	—4	2
140	—2	—5
158	0	—7
176	2	—6
194	2	—2
212	0	0

Vapor Pressure. As mentioned previously, the values of vapor pressure recommended by the Third International Steam Table Conference[20] are not as reliable in the low temperature range as desired for the construction of standard moist air tables. Thus the assigned tolerances are 0.05 per cent at 90 C and 0.10 per cent at OC. But the *Bureau of Standards*[16] measurements of γ have an uncertainty probably less than 0.01 per cent from 0 to 100 C which fact suggests the possibility of calculating the vapor pressure from (8.10) and (8.11) using the expressions (8.4) and (8.7) (with $C_o = C_1 = O$) for the virial coefficients in (8.11).

Details of this calculation will be omitted, but the final expression for the temperature derivative of $\log_{10} p_s$ is given as follows:

$$\frac{d \log_{10} p_s}{dT} = \frac{5308.90 + 1720\, e^{-4124\,\tau} + 1.6945\, e^{11.8776 - 8652.0\tau}}{T^2} - \frac{2.18362}{T} + 4.2 \times 10^{-6}\, e^{-0.05\,(t-32)} + f(t) \ldots (T \text{ in } ^\circ\text{R}) \quad \ldots\ldots 9.1$$

where the residual $f(t)$ is best handled numerically, being very small. This expression can be integrated downward from 212 F where the vapor pressure is exactly one atmosphere by definition to obtain values of $\log_{10} p_s$ where p_s is expressed in atmospheres. However, it serves no important purpose to write out the resulting expression so the matter will be left with a tabulation of the residual $f(t)$ and its integral as given in Table 2.

It is believed that the uncertainty in values of $\log_{10} p_s$ calculated from (9.1) and Table 2 is not greater than 0.01 per cent. All values are well within the tolerances set by the Third International Steam Tables Conference.[20]

Vapor Pressure of Ice. Goff[30] has recently calculated the vapor pressure of ice from the Clapeyron relation

$$T \frac{dp_s}{dT} = \frac{h_v - h_i}{v_v - v_i} \quad \ldots\ldots 10.1$$

The authors have repeated these calculations using the present information regarding virial coefficients. Integration of (10.1) gives values of $\log_{10}(p_s/p_o)$, *where* p_o denotes the vapor pressure at 32 F, in substantial agreement with the previously published results.

According to International Critical Tables,[31] the triple point where the vapor pressure of ice is identical with that of the liquid, is at 32.0176 F. At 32 F the vapor pressure of the liquid is 0.0060281 atm according to the integral of (9.1). From two writings of the Clapeyron relation, one for equilibrium between vapor and ice and one for equilibrium between vapor and liquid, the difference between the vapor pressure of liquid and that of ice at 32 F can be estimated. The answer is 0.0000006 atm; accordingly the value assigned to p_o is 0.0060275 atm.

It is believed that the uncertainty in the recalculated values of $\log_{10}(p_s/p_o)$ is about 0.02 per cent. This is equivalent to an uncertainty in p_s itself of about 0.13 per cent at —40 F and about 0.34 per cent at —160 F. Harrison[32] has shown that the previously calculated values of p_s agree very well with existing experimental data.

Other Steam Properties. Since $\bar{u}_w$ has been determined and the virial coefficients B_{ww} and B_{www} formulated, values of saturation enthalpy of the vapor h_g can be calculated from (8.3) in the range 32 to 212 F. Dividing the value thus obtained for 32 F by the absolute temperature gives a value of saturation entropy s_g to be used in fixing the constant $\bar{s}_w$ in

$$s_g = -R \log_e p_s + (\bar{s}^\circ_w - \bar{s}_w) + c_{ww} p_s + \tfrac{1}{2} c_{www} p_s^2 + \bar{s}_w \quad \ldots\ldots\ldots 11.1$$

after which values of s_g can be computed at other temperatures in the above range.

Values of saturation volume v_g are to be obtained from (8.11).

Summary. Values of second and third virial coefficients for water have been distilled from (1) zero-pressure enthalpies obtained from a critical review of existing state-sum calculations based on spectroscopic data, (2) saturation enthalpies measured calorimetrically and with high precision at the *Bureau of Standards*, (3) isothermal Joule-Thomson coefficients measured by Collins and Keyes, (4) values of vapor pressure above 95 C from Osborne and Meyers, (5) values of the calorimetric quantity γ measured at the *Bureau of Standards*, (6) the best value of the ratio of the absolute to the international kilowatt-hour as recently recommended by the *Bureau of Standards* (1.00019).

From the above data the vapor pressure of liquid water was calculated for the range 32 to 212 F with an estimated uncertainty of only 0.01 per cent in the logarithm of the vapor pressure (in atmospheres) over the whole range. The vapor pressure of ice has been recalculated from additional data on (1) latent heat of fusion at 32 F and atmospheric pressure reported by Osborne, (2) thermal coefficient of expansion by Jakob and Erk, (3) the specific volume at 32 F from Keenan and Keyes, (4) specific heat at atmospheric pressure from Giaque and Stout. The range of the recalculations is —160 to 32 F with an estimated uncertainty of only 0.02 per cent in the logarithm of the ratio of the vapor pressure to that at the triple point.

Finally, other steam properties have been calculated and will be proposed as a revision of existing steam tables in the low temperature range.

III. Moist Air

Theory of Gas Mixtures. Statistical mechanics predicts that at sufficiently low pressure p the specific volume of a gas mixture is given as to form by the equation,

$$pv = RT - p \sum_{ik} x_i x_k A_{ik}(T) \quad \ldots 13.1$$

where x_i denotes mol fraction of constituent i, x_k denotes mol fraction of constituent k, $A_{ik}(T)$ denotes second virial coefficient if $i = k$, interaction coefficient if i is unequal to k. It is clear that the coefficients $A_{ik}(T)$ express the effects of interaction between *pairs* of molecules, *like* pairs if $i = k$ and *unlike* pairs if i is unequal to k, and that the sum extends over all pairs with the understanding, of course, that $A_{ik}(T) = A_{ki}(T)$.

If (13.1) be applied to a pure gas by putting all mol fractions except number one equal to zero and putting number one equal to unity, the result is

$$pv = RT - A_{11}(T)\, p \quad \ldots\ldots 13.2$$

Unfortunately, the discussion of the preceding section has shown that (13.2) cannot accurately represent the properties of saturated water vapor at temperatures much above 150 F where a term in pressure squared of the form $-A_{111}(T)p^2$ must be added. By analogy it may be supposed that $A_{111}(T)$ expresses the effect of interaction between members of a group of three like molecules; it is called the third virial coefficient.

We know of no valid information, either theoretical or experimental, as to how (13.1) should be modified to include the effect of interaction between three-member groups of molecules, but have assumed by analogy (but nevertheless quite arbitrarily) that a proper modification is

$$pv = RT - p \sum_{ik} x_i x_k A_{ik}(T) - p^2 \sum_{ijk} x_i x_j x_k A_{ijk}(T) \quad \ldots 13.3$$

Corresponding expressions for specific enthalpy h, specific entropy s, and the chemical potentials μ_i are obtained from (13.3) by application of appropriate identical relations of thermodynamics together with predictions of statistical mechanics regarding the additivity of zero-pressure properties as follows:

$$h = \sum_i x_i h_i^\circ - p \sum_{ik} x_i x_k B_{ik} - \tfrac{1}{2} p^2 \sum_{ijk} x_i x_j x_k B_{ijk} \quad \ldots\ldots 13.4$$

$$s + R \log_e p = \sum_i x_i s_i^\circ - R \sum_i x_i \log_e x_i + p \sum_{ik} x_i x_k C_{ik} + \tfrac{1}{2} p^2 \sum_{ijk} x_i x_j x_k C_{ijk} \quad \ldots\ldots 13.5$$

$$\mu_i = g_i^\circ (T) + RT \log_e (x_i p) + p \left[\sum_{ik} x_i x_k A_{ik} - 2 \sum_k x_k A_{ik}\right]$$
$$+ \tfrac{1}{2} p^2 \left[2 \sum_{ijk} x_i x_j x_k A_{ijk} - 3 \sum_{jk} x_j x_k A_{ijk}\right] \quad \ldots\ldots 13.6$$

where as before

$$B = d(A\tau)/d\tau \quad \ldots\ldots 3.2$$

$$C = dA/dT \quad \ldots\ldots 3.3$$

and *where* $g_i^\circ(T)$ is the zero-pressure reduced specific free enthalpy, namely,

$$g_i^\circ = h_i^\circ - T s_i^\circ \quad \ldots\ldots 13.7$$

To use (13.3) to (13.6) in calculating properties of moist air would require information on the coefficients A_{aaa}, A_{aaw}, A_{aww}, A_{www}. As shown in Section I, the first of these, together with its derivatives B_{aaa} and C_{aaa}, are negligible in the range of temperature and pressure considered. Suitable values of the last, together with its derivatives B_{www} and C_{www}, have been deduced in Section II. But there exists no information, either experimental or theoretical, regarding A_{aaw}, A_{aww}, and their respective derivatives. This means that our calculated properties of moist air above 150 F must be offered with some reservations as to accuracy and permanence. What we have done is to neglect the coefficients A_{aaw} and A_{aww} entirely and write

$$pv = RT - [x^2 A_{aa} + x(1-x)\, 2\, A_{aw} + (1-x)^2 A_{ww}]\, p$$
$$- [(1-x)^3 A_{www}]\, p^2 \quad \ldots\ldots 13.8$$

$$h = [x h_a^\circ + (1-x)\, h_w^\circ] - [x^2 B_{aa} + x(1-x)\, 2\, B_{aw} + (1-x)^2 B_{ww}]\, p$$
$$- \tfrac{1}{2} [(1-x)^3 B_{www}]\, p^2 \quad \ldots\ldots 13.9$$

$$s + R \log_e p = [x s_a^\circ + (1-x)\, s_w^\circ] - R\,[x \log_e x + (1-x) \log_e (1-x)]$$
$$+ [x^2 C_{aa} + x(1-x)\, 2\, C_{aw} + (1-x)^2 C_{ww}]\, p +$$
$$\tfrac{1}{2} [(1-x)^3 C_{www}]\, p^2 \quad \ldots\ldots 13.10$$

$$\mu_a = g_a^\circ + RT \log_e (xp) + [(A_{ww} - 2A_{aw} + A_{ww})(1-x)^2 - A_{aa}]\, p$$
$$+ [(1-x)^3 A_{www}]\, p^2 \quad \ldots\ldots 13.11$$

$$\mu_w = g_w^\circ + RT \log_e (1-x), + [A_{ww} - 2A_{aw} + A_{ww})\, x^2 - A_{ww}]\, p$$
$$- [(1-x)^2 (\tfrac{1}{2} + x)\, A_{www}]\, p^2 \quad \ldots\ldots 13.12$$

where x denotes the mol fraction of dry air and $(1-x)$ that of water vapor.

Saturation. When two distinct phases, say liquid and vapor or solid and vapor, coexist, each is said to be saturated with respect to the other. From general thermodynamic reasoning the conditions for saturation are found to be equality between the two coexisting phases of (1) pressure, (2) temperature, and (3) each component chemical potential. Expressions for the chemical potentials of dry air and water in the vapor phase are given by (13.11) and (13.12), respectively. It remains, therefore, to obtain suitable expressions for these component chemical potentials in the condensed phase.

Actually the condensed phase in the present problem is almost pure water but containing a very small amount of dissolved (and oxygen enriched) air. For the purpose of analysis, the condensed phase can be regarded as an ideal, incompressible solution whose composition can be specified by x', the mol fraction of dry air. For such a solution the component chemical potentials are given as to form by

$$\mu_a' = RT \log_e x' + \overline{V}_a' p + g_a' (T) \quad \ldots\ldots 14.1$$

$$\mu_w' = RT \log_e (1-x') + \overline{V}_w' p + g_w' (T) \quad \ldots\ldots 14.2$$

where $\overline{V}_a'$ and $\overline{V}_w'$ denote component partial molal volumes, and the prime refers to the condensed phase.

One condition for saturation is obtained by equating (13.11) and (14.1), and it may be reduced to the form,

$$x_a' = k' (T)\, x_a\, p \quad \ldots\ldots 14.3$$

where, strictly speaking, $k'(T)$ should depend on pressure as well as temperature though empirically its pressure dependence is found to be extremely slight and is, therefore, neglected in the following analysis.

Another condition for saturation is obtained by equating (13.12) and (14.2) and replacing $\log_e(1-x_a')$ by $-x_a'$ which is justified by the smallness of x_a' compared with unity. The result is

$$RT \log_e [(1-x_a)\, p] =$$
$$- RT k' (T)\, x_a'\, p + \overline{V}'_w\, p$$
$$- [(A_{aa} - 2A_{aw} + A_{ww}) x_a^2 - A_{ww}]\, p$$
$$+ [(1-x_a)^2 (\tfrac{1}{2} + x_a)\, A_{www}]\, p^2$$
$$+ [g_w' (T) - g_w^\circ (T)] \quad \ldots\ldots 14.4$$

The additional conditions of equality, between the two coexisting phases, of pressure p and temperature T, have been applied in deriving (14.4) itself.

Now the temperature functions $g_w'(T)$ and $g_w^\circ(T)$ can be eliminated in favor of vapor pressure p_s (of pure water) by noting that for $p = p_s$, $x_a = x_a' = 0$. Thus, (14.4) becomes

$$RT \log_e \left[\frac{(1-x_a)\, p}{p_s}\right] =$$
$$- RT k' x_a p + \overline{V}_w' (p - p_s)$$
$$- [(A_{aa} - 2A_{aw} + A_{ww}) x_a^2]\, p$$
$$+ A_{ww} (p - p_s)$$
$$+ [A_{www} (x_a - 3/2)\, x_a^2]\, p^2$$
$$+ \tfrac{1}{2} A_{www} (p^2 - p_s^2) \quad \ldots\ldots 14.5$$

and determines mol fraction x_a as a function of pressure p and tem-

perature T, since p_s is itself a known temperature function. Since x_s appears on both sides, a trial-by-error calculation would be required to get an arbitrarily precise solution (14.5), but such calculations clearly indicate that a sufficiently precise solution is obtained by substituting $(1 - p_s/p)$ for x_s in the right-hand side. Such substitution and subsequent division by RT reduce (14.5) to

$$\log_e\left[\frac{(1-x_s)\,p}{p_s}\right] = \left(\frac{\overline{V}_w'\,p_s}{RT} - k'\,p_s\right)\left(\frac{p}{p_s} - 1\right) +$$

$$\left(\frac{2\,A_{aw}\,p_s}{RT} - \frac{A_{aa}\,p_s}{RT}\right)\left(\frac{p}{p_s} - 2 + \frac{p_s}{p}\right) + \left(\frac{A_{www}\,p_s}{RT} + \frac{A_{www}\,p_s^2}{RT}\right)\left(1 - \frac{p_s}{p}\right) \quad ..14.6$$

The Coefficients $\overline{V}_w'$ and $k'(T)$. At saturation the condensed phase is almost pure water. Therefore, the partial molal volume $\overline{V}_w'$ does not differ appreciably from the specific volume v_f (or v_i) of pure saturated liquid (or solid) water. Values of the solubility coefficient $k'(T)$ for the liquid phase have been taken from *International Critical Tables*[33]; those for the solid phase have been assumed zero since the solubility of air in ice is negligibly small.

The Interaction Cofficient A_{aw}. A considerable portion of the cooperative investigation referred to in the introduction to this paper was devoted to an experimental measurement of the interaction coefficient A_{aw}. The experiment devised for the purpose has been called the two-stage, saturation-isotherm experiment and has been described in a previous paper.[34] In it a continuous sample of dry, carbon dioxide-free air was passed through a suitable saturator from which it left at a closely regulated pressure p_1, thence through a reducing valve, thence through a drying train in which m_1 pounds of water picked up in the saturator was removed (during the test period), thence through a second saturator from which it left at a closely regulated pressure p_2, thence through a second drying train in which m_2 pounds of water was removed (during the same period), thence to the suction of a vacuum pump discharging to atmosphere. Both saturators were located in a single thermostated bath so that the air was saturated twice at the same temperature T, but at two different pressures.

If the weight of dry air m_a passing through the apparatus during the test period had been measured with sufficiently high precision, the mol fractions x_1 and x_2 could have been calculated and corresponding values of A_{aw} computed from two writings of (14.6), one for saturation at pressure p_1 and the other for pressure p_2. These two computed values should be identical since A_{aw} is supposed to depend on temperature only, but actually the common temperature was not measured with sufficient accuracy to enable this method to yield reliable results. Alternatively, m_a was eliminated between the two writings of (14.6), leaving A_{aw} as the only unknown and making the value computed in this manner practically unaffected by slight inaccuracies in the measurements of temperature and weight of dry air.

The results obtained in the above manner but with less reliable values of the properties of dry air and water vapor have been published previously.[7] Recalculated values are shown in Table 3.

Table 3—Interaction Coefficient for Moist Air

t (deg C)	$\lambda = \frac{2\,A_{aw}}{A_{aa} + A_{ww}}$	A_{aw} (ft³/mol)
5	0.048	0.64 ± 0.03
15	0.054	0.61 ± 0.03
20	0.060	0.61 ± 0.03
25	0.059	0.54 ± 0.03

In a previous paper[7] it was shown that surprisingly close agreement with the experimental values of A_{aw} was obtained from the theoretical expression (2.5) using the *rigid sphere* model for expressing $E_{aw}(r)$ in terms of distance of separation r, choosing for r_0 the arithmetic mean of the corresponding r_0-values found for dry air and water vapor separately as suggested by Fowler,[35] and determining the coefficients a_3, a_4, a_5 in (2.6) from corresponding coefficients for dry air and water vapor by means of combination rules suggested by the theory. Fortunately, (2.5) is applicable to the calculation of A_{aw} even though it is not to A_{aaa}, because the interaction potential E_{aw} is not appreciably affected by the polar character of the water molecule and can therefore be regarded as a function of distance of separation only.

The close agreement referred to encouraged us to improve upon the rigid sphere model in order to use the theory for the necessary extrapolation of A_{aw} well outside the experimental range of temperature. The improvement consisted of expressing the contribution to $E_{aw}(r)$ from short-range repulsive forces in the form $P_{aw}e^{-r/\rho_{aw}}$, assigning ρ_{aw} the value 0.28×10^{-8} cm *a priori*, determining the coefficients a_3, a_4, a_5 from the data of Margenau,[1] and adjusting P_{aw} to fit the experimental data in Table 3. The various constants used are listed below.

$$\left.\begin{aligned} P_{aw} &= 3.4337 \times 10^{-9}\ \text{erg} \\ \rho_{aw} &= 0.28 \times 10^{-8}\ \text{cm} \\ a_3 &= 54.7 \times 10^{-60}\ \text{erg cm}^6 \\ a_4 &= 114.9 \times 10^{-76}\ \text{erg cm}^8 \\ a_5 &= 127.9 \times 10^{-92}\ \text{erg cm}^{10} \end{aligned}\right\} 16.1$$

The above constants place the potential minimum very near 3.230×10^{-8} cm, the value of r_0 obtained for the rigid sphere model in the manner explained above. Fig. 3

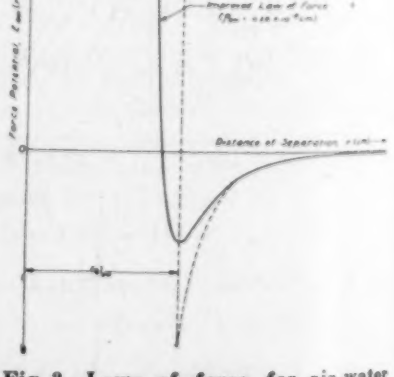

Fig. 3—Laws of force for air-water interaction

Table 4—Thermodynamic Properties of Moist Air (Standard Atmospheric Pressure, 29.921 in. Hg)

Temp. °F	Humidity Ratio $W_s \times 10^2$	Volume cu ft/lb dry air v_a	v_{as}	v_s	Enthalpy Btu/lb dry air h_a	h_{as}	h_s	Entropy Btu/°F lb dry air s_a	s_{as}	s_s	Condensed Water Enthalpy Btu/lb h'_w	Entropy Btu/lb°F s'_w	Vap. Press. in. Hg $p_s \times 10^5$	Temp. °F
-160	0.2120	7.520	0.000	7.520	-38.504	0.000	-38.504	-0.10300	0.00000	-0.10300	-222.00	-0.4907	0.1009	-160
-159	0.2394	7.545	0.000	7.545	-38.262	0.000	-38.262	-0.10219	0.00000	-0.10219	-221.68	-0.4896	0.1139	-159
-158	0.2703	7.571	0.000	7.571	-38.021	0.000	-38.021	-0.10139	0.00000	-0.10139	-221.36	-0.4885	0.1286	-158
-157	0.3049	7.596	0.000	7.596	-37.779	0.000	-37.779	-0.10059	0.00000	-0.10059	-221.04	-0.4874	0.1450	-157
-156	0.3435	7.622	0.000	7.622	-37.538	0.000	-37.538	-0.09980	0.00000	-0.09980	-220.72	-0.4864	0.1635	-156
-155	0.3869	7.647	0.000	7.647	-37.296	0.000	-37.296	-0.09901	0.00000	-0.09901	-220.40	-0.4853	0.1842	-155
-154	0.4354	7.673	0.000	7.673	-37.055	0.000	-37.055	-0.09822	0.00000	-0.09822	-220.07	-0.4843	0.2073	-154
-153	0.4897	7.699	0.000	7.699	-36.813	0.000	-36.813	-0.09743	0.00000	-0.09743	-219.75	-0.4832	0.2331	-153
-152	0.5502	7.724	0.000	7.724	-36.572	0.000	-36.572	-0.09664	0.00000	-0.09664	-219.42	-0.4822	0.2620	-152
-151	0.6178	7.750	0.000	7.750	-36.330	0.000	-36.330	-0.09586	0.00000	-0.09586	-219.10	-0.4811	0.2942	-151
-150	0.6932	7.775	0.000	7.775	-36.088	0.000	-36.088	-0.09508	0.00000	-0.09508	-218.77	-0.4800	0.3301	-150
-149	0.7772	7.801	0.000	7.801	-35.847	0.000	-35.847	-0.09430	0.00000	-0.09430	-218.44	-0.4789	0.3701	-149
-148	0.8709	7.826	0.000	7.826	-35.606	0.000	-35.606	-0.09352	0.00000	-0.09352	-218.11	-0.4779	0.4146	-148
-147	0.9750	7.851	0.000	7.851	-35.364	0.000	-35.364	-0.09274	0.00000	-0.09274	-217.78	-0.4768	0.4641	-147
-146	1.091	7.876	0.000	7.876	-35.123	0.000	-35.123	-0.09198	0.00000	-0.09198	-217.45	-0.4758	0.5194	-146
-145	1.219	7.902	0.000	7.902	-34.881	0.000	-34.881	-0.09121	0.00000	-0.09121	-217.12	-0.4747	0.5807	-145
-144	1.362	7.927	0.000	7.927	-34.640	0.000	-34.640	-0.09044	0.00000	-0.09044	-216.78	-0.4737	0.6488	-144
-143	1.521	7.953	0.000	7.953	-34.399	0.000	-34.399	-0.08967	0.00000	-0.08967	-216.45	-0.4726	0.7243	-143
-142	1.698	7.978	0.000	7.978	-34.157	0.000	-34.157	-0.08892	0.00000	-0.08892	-216.11	-0.4716	0.8082	-142
-141	1.893	8.004	0.000	8.004	-33.916	0.000	-33.916	-0.08816	0.00000	-0.08816	-215.78	-0.4705	0.9011	-141
-140	2.109	8.029	0.000	8.029	-33.674	0.000	-33.674	-0.08740	0.00000	-0.08740	-215.44	-0.4695	1.004	-140
-139	2.348	8.054	0.000	8.054	-33.433	0.000	-33.433	-0.08664	0.00000	-0.08664	-215.11	-0.4684	1.118	-139
-138	2.613	8.079	0.000	8.079	-33.192	0.000	-33.192	-0.08589	0.00000	-0.08589	-214.77	-0.4674	1.244	-138
-137	2.906	8.105	0.000	8.105	-32.951	0.000	-32.951	-0.08514	0.00000	-0.08514	-214.43	-0.4663	1.383	-137
-136	3.229	8.130	0.000	8.130	-32.709	0.000	-32.709	-0.08440	0.00000	-0.08440	-214.09	-0.4653	1.537	-136
-135	3.586	8.156	0.000	8.156	-32.468	0.000	-32.468	-0.08365	0.00000	-0.08365	-213.75	-0.4642	1.707	-135
-134	3.980	8.181	0.000	8.181	-32.226	0.000	-32.226	-0.08291	0.00000	-0.08291	-213.41	-0.4632	1.895	-134
-133	4.414	8.207	0.000	8.207	-31.985	0.000	-31.985	-0.08217	0.00000	-0.08217	-213.07	-0.4621	2.102	-133
-132	4.893	8.232	0.000	8.232	-31.744	0.000	-31.744	-0.08144	0.00000	-0.08144	-212.72	-0.4611	2.330	-132
-131	5.419	8.258	0.000	8.258	-31.503	0.000	-31.503	-0.08070	0.00000	-0.08070	-212.38	-0.4600	2.581	-131

Temp. °F	Humidity Ratio $W_s \times 10^5$	Volume cu ft/lb dry air v_a	v_{as}	v_s	Enthalpy Btu/lb dry air h_a	h_{as}	h_s	Entropy Btu/°F lb dry air s_a	s_{as}	s_s	Condensed Water Enthalpy Btu/lb h'_w	Entropy Btu/lb°F s'_w	Vap. Press. in. Hg $p_s \times 10^4$	Temp. °F
-130	0.6000	8.283	0.000	8.283	-31.262	0.000	-31.262	-0.07997	0.00000	-0.07997	-212.03	-0.4590	0.2858	-130
-129	0.6637	8.309	0.000	8.309	-31.021	0.000	-31.021	-0.07924	0.00000	-0.07924	-211.68	-0.4579	0.3182	-129
-128	0.7339	8.334	0.000	8.334	-30.780	0.000	-30.780	-0.07851	0.00000	-0.07851	-211.33	-0.4569	0.3492	-128
-127	0.8111	8.360	0.000	8.360	-30.539	0.000	-30.539	-0.07778	0.00000	-0.07778	-210.98	-0.4559	0.3863	-127
-126	0.8958	8.385	0.000	8.385	-30.298	0.000	-30.298	-0.07707	0.00000	-0.07707	-210.63	-0.4548	0.4267	-126
-125	0.9887	8.411	0.000	8.411	-30.057	0.000	-30.057	-0.07634	0.00000	-0.07634	-210.28	-0.4538	0.4710	-125
-124	1.091	8.436	0.000	8.436	-29.816	0.000	-29.816	-0.07562	0.00000	-0.07562	-209.93	-0.4527	0.5197	-124
-123	1.202	8.461	0.000	8.461	-29.575	0.000	-29.575	-0.07490	0.00000	-0.07490	-209.58	-0.4517	0.5730	-123
-122	1.325	8.486	0.000	8.486	-29.334	0.000	-29.334	-0.07419	0.00000	-0.07419	-209.23	-0.4506	0.6314	-122
-121	1.459	8.512	0.000	8.512	-29.093	0.000	-29.093	-0.07348	0.00000	-0.07348	-208.88	-0.4496	0.6953	-121
-120	1.606	8.537	0.000	8.537	-28.852	0.000	-28.852	-0.07277	0.00000	-0.07277	-208.52	-0.4485	0.7653	-120
-119	1.767	8.563	0.000	8.563	-28.611	0.000	-28.611	-0.07206	0.00000	-0.07206	-208.17	-0.4475	0.8419	-119
-118	1.942	8.588	0.000	8.588	-28.370	0.000	-28.370	-0.07135	0.00000	-0.07135	-207.81	-0.4464	0.9256	-118
-117	2.134	8.613	0.000	8.613	-28.129	0.000	-28.129	-0.07064	0.00000	-0.07064	-207.45	-0.4454	1.017	-117
-116	2.343	8.639	0.000	8.639	-27.889	0.000	-27.889	-0.06994	0.00000	-0.06994	-207.09	-0.4444	1.117	-116
-115	2.571	8.664	0.000	8.664	-27.648	0.000	-27.648	-0.06924	0.00000	-0.06924	-206.73	-0.4433	1.226	-115
-114	2.820	8.690	0.000	8.690	-27.407	0.000	-27.407	-0.06854	0.00000	-0.06854	-206.37	-0.4423	1.345	-114
-113	3.092	8.715	0.000	8.715	-27.166	0.000	-27.166	-0.06784	0.00000	-0.06784	-206.01	-0.4412	1.475	-113
-112	3.388	8.741	0.000	8.741	-26.926	0.000	-26.926	-0.06715	0.00000	-0.06715	-205.65	-0.4402	1.617	-112
-111	3.711	8.766	0.000	8.766	-26.685	0.000	-26.685	-0.06646	0.00000	-0.06646	-205.29	-0.4392	1.771	-111
-110	4.063	8.792	0.000	8.792	-26.444	0.000	-26.444	-0.06577	0.00000	-0.06577	-204.92	-0.4381	1.939	-110
-109	4.445	8.817	0.000	8.817	-26.204	0.000	-26.204	-0.06508	0.00000	-0.06508	-204.46	-0.4371	2.121	-109
-108	4.861	8.842	0.000	8.842	-25.963	0.001	-25.962	-0.06439	0.00000	-0.06439	-204.19	-0.4360	2.320	-108
-107	5.314	8.868	0.000	8.868	-25.722	0.001	-25.721	-0.06370	0.00000	-0.06370	-203.83	-0.4350	2.536	-107
-106	5.806	8.893	0.000	8.893	-25.481	0.001	-25.480	-0.06302	0.00000	-0.06302	-203.46	-0.4339	2.771	-106
-105	6.340	8.919	0.000	8.919	-25.240	0.001	-25.239	-0.06234	0.00000	-0.06234	-203.09	-0.4329	3.026	-105
-104	6.920	8.944	0.000	8.944	-25.000	0.001	-24.999	-0.06167	0.00000	-0.06167	-202.72	-0.4318	3.303	-104
-103	7.549	8.970	0.000	8.970	-24.759	0.001	-24.758	-0.06099	0.00000	-0.06099	-202.35	-0.4308	3.603	-103
-102	8.232	8.995	0.000	8.995	-24.518	0.001	-24.517	-0.06032	0.00000	-0.06032	-201.98	-0.4298	3.929	-102
-101	8.972	9.020	0.000	9.020	-24.278	0.001	-24.277	-0.05964	0.00000	-0.05964	-201.61	-0.4287	4.283	-101

Temp. °F	Humidity Ratio $W_s \times 10^5$	Volume cu ft/lb dry air v_a	v_{as}	v_s	Enthalpy Btu/lb dry air h_a	h_{as}	h_s	Entropy Btu/°F lb dry air s_a	s_{as}	s_s	Condensed Water Enthalpy Btu/lb h'_w	Entropy Btu/lb°F s'_w	Vap. Press. in. Hg $p_s \times 10^4$	Temp. °F
-100	0.9772	9.046	0.000	9.046	-24.037	0.001	-24.036	-0.05897	0.00000	-0.05897	-201.23	-0.4277	0.4666	-100
-99	1.063	9.071	0.000	9.071	-23.797	0.001	-23.796	-0.05830	0.00000	-0.05830	-200.86	-0.4266	0.5081	-99
-98	1.157	9.097	0.000	9.097	-23.556	0.001	-23.555	-0.05764	0.00000	-0.05764	-200.48	-0.4256	0.5530	-98
-97	1.259	9.122	0.000	9.122	-23.316	0.001	-23.315	-0.05697	0.00000	-0.05697	-200.11	-0.4245	0.6016	-97
-96	1.369	9.147	0.000	9.147	-23.075	0.001	-23.074	-0.05631	0.00000	-0.05631	-199.73	-0.4235	0.6542	-96
-95	1.489	9.173	0.000	9.173	-22.835	0.002	-22.833	-0.05565	0.00000	-0.05565	-199.35	-0.4225	0.7111	-95
-94	1.617	9.198	0.000	9.198	-22.594	0.002	-22.592	-0.05500	0.00000	-0.05500	-198.97	-0.4214	0.7725	-94
-93	1.756	9.224	0.000	9.224	-22.353	0.002	-22.341	-0.05434	0.00000	-0.05434	-198.59	-0.4204	0.8388	-93
-92	1.906	9.249	0.000	9.249	-22.113	0.002	-22.111	-0.05369	0.00001	-0.05368	-198.21	-0.4193	0.9105	-92
-91	2.068	9.275	0.000	9.275	-21.872	0.002	-21.870	-0.05303	0.00001	-0.05302	-197.83	-0.4183	0.9879	-91
-90	2.242	9.300	0.000	9.300	-21.631	0.002	-21.629	-0.05237	0.00001	-0.05236	-197.44	-0.4173	1.071	-90
-89	2.430	9.325	0.000	9.325	-21.391	0.003	-21.388	-0.05172	0.00001	-0.05171	-197.06	-0.4162	1.161	-89
-88	2.634	9.351	0.000	9.351	-21.150	0.003	-21.147	-0.05107	0.00001	-0.05106	-196.67	-0.4152	1.259	-88
-87	2.852	9.376	0.000	9.376	-20.909	0.003	-20.906	-0.05042	0.00001	-0.05041	-196.29	-0.4142	1.363	-87
-86	3.089	9.401	0.000	9.401	-20.669	0.003	-20.666	-0.04978	0.00001	-0.04977	-195.90	-0.4131	1.476	-86
-85	3.342	9.426	0.000	9.426	-20.428	0.003	-20.425	-0.04913	0.00001	-0.04912	-195.51	-0.4121	1.597	-85
-84	3.615	9.451	0.000	9.451	-20.188	0.004	-20.184	-0.04849	0.00001	-0.04848	-195.12	-0.4110	1.728	-84
-83	3.909	9.477	0.000	9.477	-19.947	0.004	-19.943	-0.04785	0.00001	-0.04784	-194.73	-0.4100	1.868	-83
-82	4.225	9.502	0.000	9.502	-19.706	0.004	-19.702	-0.04721	0.00001	-0.04720	-194.34	-0.4090	2.019	-82
-81	4.564	9.527	0.000	9.527	-19.466	0.005	-19.461	-0.04658	0.00001	-0.04657	-193.95	-0.4079	2.181	-81
-80	4.930	9.553	0.000	9.553	-19.225	0.005	-19.220	-0.04595	0.00001	-0.04594	-193.55	-0.4069	2.356	-80
-79	5.322	9.578	0.000	9.578	-18.984	0.005	-18.979	-0.04532	0.00002	-0.04530	-193.16	-0.4059	2.543	-79
-78	5.742	9.604	0.000	9.604	-18.744	0.006	-18.738	-0.04469	0.00002	-0.04467	-192.76	-0.4048	2.744	-78
-77	6.193	9.629	0.000	9.629	-18.503	0.006	-18.497	-0.04406	0.00002	-0.04404	-192.37	-0.4038	2.960	-77
-76	6.677	9.654	0.000	9.654	-18.263	0.007	-18.256	-0.04343	0.00002	-0.04341	-191.97	-0.4027	3.192	-76
-75	7.146	9.680	0.000	9.680	-18.022	0.007	-18.015	-0.04280	0.00002	-0.04278	-191.57	-0.4017	3.441	-75
-74	7.753	9.705	0.000	9.705	-17.782	0.008	-17.774	-0.04218	0.00003	-0.04215	-191.17	-0.4007	3.707	-74
-73	8.349	9.730	0.000	9.730	-17.541	0.008	-17.533	-0.04155	0.00003	-0.04152	-190.77	-0.3996	3.992	-73
-72	8.990	9.756	0.000	9.756	-17.301	0.009	-17.292	-0.04093	0.00003	-0.04090	-190.37	-0.3986	4.298	-72
-71	9.675	9.781	0.000	9.781	-17.060	0.010	-17.050	-0.04031	0.00003	-0.04028	-189.97	-0.3975	4.625	-71

Temp. °F	Humidity Ratio $W_s \times 10^5$	Volume cu ft/lb dry air v_a	v_{as}	v_s	Enthalpy Btu/lb dry air h_a	h_{as}	h_s	Entropy Btu/°F lb dry air s_a	s_{as}	s_s	Condensed Water Enthalpy Btu/lb h'_w	Entropy Btu/lb°F s'_w	Vap. Pr. in Hg $p_s \times 10^3$	Temp °F
-70	1.040	9.806	0.000	9.806	-16.820	0.011	-16.809	-0.03969	0.00003	-0.03966	-189.56	-0.3965	0.4976	-70
-69	1.119	9.831	0.000	9.831	-16.579	0.011	-16.568	-0.03908	0.00004	-0.03904	-189.16	-0.3954	0.5351	-69
-68	1.203	9.856	0.000	9.856	-16.339	0.012	-16.327	-0.03846	0.00004	-0.03842	-188.75	-0.3944	0.5752	-68
-67	1.292	9.882	0.000	9.882	-16.098	0.013	-16.085	-0.03785	0.00004	-0.03781	-188.35	-0.3934	0.6181	-67
-66	1.388	9.907	0.000	9.907	-15.858	0.014	-15.844	-0.03724	0.00004	-0.03720	-187.94	-0.3924	0.6640	-66
-65	1.491	9.932	0.000	9.932	-15.617	0.015	-15.602	-0.03663	0.00005	-0.03659	-187.53	-0.3913	0.7130	-65
-64	1.601	9.958	0.000	9.958	-15.377	0.016	-15.361	-0.03602	0.00005	-0.03597	-187.12	-0.3903	0.7654	-64
-63	1.718	9.983	0.000	9.983	-15.137	0.018	-15.119	-0.03541	0.00005	-0.03536	-186.71	-0.3893	0.8213	-63
-62	1.843	10.009	0.000	10.009	-14.896	0.019	-14.877	-0.03481	0.00005	-0.03475	-186.30	-0.3882	0.8810	-62
-61	1.976	10.034	0.000	10.034	-14.656	0.020	-14.636	-0.03420	0.00006	-0.03414	-185.89	-0.3872	0.9447	-61
-60	2.118	10.059	0.000	10.059	-14.416	0.022	-14.394	-0.03360	0.00006	-0.03354	-185.47	-0.3861	1.0127	-60
-59	2.269	10.085	0.000	10.085	-14.175	0.023	-14.152	-0.03300	0.00007	-0.03293	-185.06	-0.3851	1.0850	-59
-58	2.431	10.110	0.000	10.110	-13.935	0.025	-13.910	-0.03240	0.00007	-0.03233	-184.64	-0.3841	1.1624	-58
-57	2.603	10.135	0.000	10.135	-13.695	0.027	-13.668	-0.03180	0.00008	-0.03172	-184.23	-0.3830	1.2447	-57
-56	2.786	10.161	0.000	10.161	-13.454	0.029	-13.425	-0.03120	0.00008	-0.03112	-183.81	-0.3820	1.3324	-56
-55	2.982	10.186	0.000	10.186	-13.214	0.031	-13.183	-0.03061	0.00009	-0.03052	-183.39	-0.3810	1.4259	-55
-54	3.190	10.211	0.000	10.211	-12.974	0.033	-12.941	-0.03002	0.00009	-0.02993	-182.97	-0.3799	1.5255	-54
-53	3.411	10.237	0.000	10.237	-12.733	0.035	-12.698	-0.02943	0.00010	-0.02933	-182.55	-0.3789	1.6312	-53
-52	3.646	10.262	0.001	10.263	-12.493	0.038	-12.455	-0.02884	0.00011	-0.02873	-182.13	-0.3779	1.7438	-52
-51	3.897	10.288	0.001	10.289	-12.253	0.041	-12.212	-0.02825	0.00011	-0.02814	-181.71	-0.3769	1.8635	-51
-50	4.163	10.313	0.001	10.314	-12.012	0.043	-11.969	-0.02766	0.00012	-0.02754	-181.29	-0.3758	1.9910	-50
-49	4.446	10.338	0.001	10.339	-11.772	0.046	-11.726	-0.02707	0.00012	-0.02695	-180.87	-0.3748	2.1264	-49
-48	4.747	10.364	0.001	10.365	-11.532	0.049	-11.483	-0.02649	0.00013	-0.02636	-180.44	-0.3738	2.2702	-48
-47	5.066	10.389	0.001	10.390	-11.292	0.053	-11.239	-0.02590	0.00013	-0.02577	-180.02	-0.3728	2.4230	-47
-46	5.406	10.414	0.001	10.415	-11.051	0.056	-10.995	-0.02532	0.00014	-0.02518	-179.59	-0.3717	2.5854	-46
-45	5.766	10.440	0.001	10.441	-10.811	0.060	-10.751	-0.02474	0.00015	-0.02459	-179.16	-0.3707	2.7578	-45
-44	6.149	10.465	0.001	10.466	-10.571	0.064	-10.507	-0.02416	0.00016	-0.02400	-178.73	-0.3696	2.9408	-44
-43	6.555	10.490	0.001	10.491	-10.330	0.068	-10.262	-0.02358	0.00017	-0.02341	-178.30	-0.3686	3.1349	-43
-42	6.985	10.516	0.001	10.517	-10.090	0.073	-10.017	-0.02301	0.00019	-0.02282	-177.87	-0.3676	3.3408	-42
-41	7.441	10.541	0.001	10.542	- 9.850	0.078	-9.772	-0.02243	0.00020	-0.02223	-177.44	-0.3665	3.5591	-41

Table 4—Thermodynamic Properties of Moist Air (Standard Atmospheric Pressure, 29.921 in. Hg)

T.D.P. °F	HUMIDITY RATIO $W_s \times 10^4$	VOLUME cu ft/lb dry air v_a	v_{as}	v_s	ENTHALPY Btu/lb dry air h_a	h_{as}	h_s	ENTROPY Btu/°F lb dry air s_a	s_{as}	s_s	CONDENSED WATER Enthalpy Btu/lb h'_w	Entropy Btu/lb°F s'_w	Vap.Press. in.Hg $p_s \times 10^2$	T.D.P. °F
-40	0.7925	10.566	0.001	10.567	-9.609	0.083	-9.526	-0.02146	0.00021	-0.02165	-177.01	-0.3655	0.37906	-40
-39	0.8437	10.592	0.001	10.593	-9.369	0.089	-9.280	-0.02129	0.00022	-0.02107	-176.58	-0.3645	0.40359	-39
-38	0.8980	10.617	0.002	10.619	-9.129	0.094	-9.035	-0.02072	0.00024	-0.02048	-176.14	-0.3634	0.42958	-38
-37	0.9556	10.642	0.002	10.644	-8.889	0.100	-8.789	-0.02015	0.00025	-0.01990	-175.71	-0.3624	0.45711	-37
-36	1.016	10.668	0.002	10.670	-8.648	0.106	-8.542	-0.01958	0.00026	-0.01932	-175.27	-0.3614	0.48626	-36
-35	1.081	10.693	0.002	10.695	-8.408	0.113	-8.295	-0.01902	0.00028	-0.01874	-174.84	-0.3604	0.51713	-35
-34	1.149	10.718	0.002	10.720	-8.168	0.121	-8.047	-0.01845	0.00030	-0.01815	-174.40	-0.3593	0.54980	-34
-33	1.221	10.744	0.002	10.746	-7.927	0.128	-7.799	-0.01788	0.00032	-0.01757	-173.96	-0.3583	0.58437	-33
-32	1.298	10.769	0.002	10.771	-7.687	0.136	-7.551	-0.01733	0.00034	-0.01699	-173.52	-0.3573	0.62093	-32
-31	1.378	10.794	0.002	10.796	-7.447	0.145	-7.302	-0.01677	0.00036	-0.01641	-173.08	-0.3563	0.65979	-31
-30	1.464	10.820	0.002	10.822	-7.207	0.154	-7.053	-0.01621	0.00038	-0.01583	-172.64	-0.3552	0.70046	-30
-29	1.554	10.845	0.003	10.848	-6.966	0.163	-6.803	-0.01565	0.00040	-0.01525	-172.20	-0.3542	0.74365	-29
-28	1.649	10.870	0.003	10.873	-6.726	0.173	-6.553	-0.01509	0.00043	-0.01466	-171.75	-0.3531	0.78928	-28
-27	1.750	10.896	0.003	10.899	-6.486	0.184	-6.302	-0.01453	0.00045	-0.01408	-171.31	-0.3521	0.83748	-27
-26	1.856	10.921	0.003	10.924	-6.246	0.196	-6.050	-0.01398	0.00048	-0.01350	-170.86	-0.3511	0.88838	-26
-25	1.969	10.946	0.004	10.950	-6.005	0.207	-5.798	-0.01342	0.00051	-0.01291	-170.42	-0.3500	0.94212	-25
-24	2.087	10.972	0.004	10.976	-5.765	0.219	-5.546	-0.01287	0.00054	-0.01233	-169.97	-0.3490	0.99885	-24
-23	2.212	10.997	0.004	11.001	-5.525	0.232	-5.293	-0.01232	0.00057	-0.01175	-169.52	-0.3480	1.0587	-23
-22	2.344	11.022	0.004	11.026	-5.285	0.246	-5.039	-0.01177	0.00061	-0.01116	-169.07	-0.3469	1.1219	-22
-21	2.483	11.048	0.004	11.052	-5.044	0.261	-4.783	-0.01122	0.00064	-0.01058	-168.62	-0.3459	1.1885	-21
-20	2.630	11.073	0.005	11.078	-4.804	0.277	-4.527	-0.01067	0.00068	-0.00999	-168.17	-0.3449	1.2587	-20
-19	2.785	11.098	0.005	11.103	-4.564	0.293	-4.271	-0.01012	0.00072	-0.00940	-167.72	-0.3439	1.3327	-19
-18	2.948	11.124	0.005	11.129	-4.324	0.310	-4.014	-0.00958	0.00076	-0.00882	-167.26	-0.3428	1.4107	-18
-17	3.120	11.149	0.006	11.155	-4.083	0.328	-3.755	-0.00904	0.00080	-0.00824	-166.81	-0.3418	1.4929	-17
-16	3.301	11.174	0.006	11.180	-3.843	0.348	-3.495	-0.00850	0.00084	-0.00766	-166.35	-0.3408	1.5795	-16
-15	3.491	11.200	0.006	11.206	-3.603	0.368	-3.235	-0.00796	0.00089	-0.00707	-165.90	-0.3398	1.6706	-15
-14	3.692	11.225	0.007	11.232	-3.363	0.389	-2.974	-0.00743	0.00094	-0.00649	-165.44	-0.3387	1.7666	-14
-13	3.903	11.250	0.007	11.257	-3.123	0.412	-2.711	-0.00689	0.00099	-0.00590	-164.98	-0.3377	1.8677	-13
-12	4.125	11.275	0.008	11.283	-2.882	0.436	-2.446	-0.00636	0.00104	-0.00532	-164.52	-0.3367	1.9740	-12
-11	4.359	11.301	0.008	11.309	-2.642	0.461	-2.181	-0.00582	0.00109	-0.00473	-164.06	-0.3357	2.0859	-11
-10	0.4606	11.326	0.008	11.334	-2.402	0.487	-1.915	-0.00529	0.00115	-0.00414	-163.60	-0.3346	2.2035	-10
-9	0.4865	11.351	0.008	11.359	-2.162	0.514	-1.648	-0.00475	0.00121	-0.00354	-163.14	-0.3336	2.3272	-9
-8	0.5137	11.376	0.009	11.385	-1.922	0.543	-1.379	-0.00422	0.00128	-0.00294	-162.67	-0.3326	2.4573	-8
-7	0.5423	11.401	0.010	11.411	-1.681	0.574	-1.107	-0.00369	0.00135	-0.00234	-162.21	-0.3316	2.5940	-7
-6	0.5724	11.427	0.010	11.437	-1.441	0.606	-0.835	-0.00316	0.00142	-0.00174	-161.74	-0.3305	2.7377	-6
-5	0.6040	11.452	0.011	11.463	-1.201	0.639	-0.562	-0.00263	0.00149	-0.00114	-161.28	-0.3295	2.8886	-5
-4	0.6371	11.477	0.012	11.489	-0.961	0.675	-0.286	-0.00210	0.00157	-0.00053	-160.81	-0.3285	3.0472	-4
-3	0.6720	11.502	0.013	11.515	-0.721	0.712	-0.009	-0.00157	0.00165	0.00008	-160.34	-0.3275	3.2137	-3
-2	0.7085	11.528	0.013	11.541	-0.480	0.751	0.271	-0.00105	0.00174	0.00069	-159.87	-0.3264	3.3885	-2
-1	0.7469	11.553	0.014	11.567	-0.240	0.792	0.552	-0.00052	0.00183	0.00131	-159.40	-0.3254	3.5720	-1
0	0.7872	11.578	0.015	11.593	0.000	0.835	0.835	0.00000	0.00192	0.00192	-158.93	-0.3244	3.7645	0
1	0.8295	11.604	0.015	11.619	0.240	0.880	1.120	0.00052	0.00202	0.00254	-158.46	-0.3234	3.9666	1
2	0.8739	11.629	0.016	11.645	0.480	0.928	1.408	0.00104	0.00212	0.00316	-157.99	-0.3223	4.1785	2
3	0.9204	11.654	0.017	11.671	0.721	0.977	1.698	0.00156	0.00223	0.00379	-157.52	-0.3213	4.4007	3
4	0.9692	11.679	0.018	11.697	0.961	1.030	1.991	0.00208	0.00234	0.00442	-157.04	-0.3203	4.6337	4
5	1.020	11.705	0.019	11.724	1.201	1.085	2.286	0.00260	0.00246	0.00506	-156.57	-0.3193	4.8779	5
6	1.074	11.730	0.020	11.750	1.441	1.142	2.583	0.00312	0.00258	0.00570	-156.09	-0.3182	5.1339	6
7	1.130	11.756	0.021	11.777	1.681	1.202	2.883	0.00364	0.00271	0.00635	-155.61	-0.3172	5.4022	7
8	1.189	11.781	0.022	11.803	1.922	1.266	3.188	0.00415	0.00285	0.00700	-155.13	-0.3162	5.6832	8
9	1.251	11.806	0.024	11.830	2.162	1.332	3.494	0.00467	0.00299	0.00766	-154.65	-0.3152	5.9776	9
10	1.315	11.831	0.025	11.856	2.402	1.401	3.803	0.00518	0.00314	0.00832	-154.17	-0.3141	6.2858	10
11	1.383	11.857	0.026	11.883	2.642	1.474	4.116	0.00569	0.00330	0.00899	-153.69	-0.3131	6.6085	11
12	1.454	11.882	0.028	11.910	2.882	1.550	4.432	0.00620	0.00346	0.00966	-153.21	-0.3121	6.9462	12
13	1.528	11.907	0.029	11.936	3.123	1.630	4.753	0.00671	0.00363	0.01034	-152.73	-0.3111	7.2997	13
14	1.606	11.933	0.030	11.963	3.363	1.713	5.076	0.00721	0.00380	0.01101	-152.24	-0.3100	7.6696	14
15	1.687	11.958	0.032	11.990	3.603	1.800	5.403	0.00772	0.00399	0.01171	-151.76	-0.3090	8.0565	15
16	1.772	11.983	0.034	12.017	3.843	1.892	5.735	0.00822	0.00418	0.01240	-151.27	-0.3080	8.4612	16
17	1.861	12.009	0.035	12.044	4.083	1.988	6.071	0.00873	0.00438	0.01311	-150.78	-0.3070	8.8843	17
18	1.953	12.034	0.038	12.072	4.324	2.088	6.412	0.00923	0.00459	0.01382	-150.29	-0.3059	9.3267	18
19	2.051	12.059	0.040	12.099	4.564	2.192	6.756	0.00973	0.00481	0.01454	-149.80	-0.3049	9.7889	19
20	2.152	12.084	0.042	12.126	4.804	2.302	7.106	0.01023	0.00504	0.01527	-149.31	-0.3039	0.10272	20
21	2.258	12.110	0.044	12.154	5.044	2.416	7.460	0.01073	0.00528	0.01601	-148.82	-0.3029	0.10777	21
22	2.369	12.135	0.046	12.181	5.284	2.536	7.820	0.01123	0.00553	0.01676	-148.33	-0.3018	0.11305	22
23	2.485	12.160	0.049	12.209	5.525	2.661	8.186	0.01173	0.00579	0.01752	-147.84	-0.3008	0.11856	23
24	2.606	12.186	0.051	12.237	5.765	2.792	8.557	0.01223	0.00607	0.01830	-147.34	-0.2998	0.12431	24
25	2.733	12.211	0.054	12.265	6.005	2.929	8.934	0.01273	0.00635	0.01908	-146.85	-0.2988	0.13032	25
26	2.865	12.236	0.057	12.293	6.245	3.072	9.317	0.01322	0.00665	0.01987	-146.35	-0.2977	0.13659	26
27	3.003	12.262	0.059	12.321	6.485	3.221	9.706	0.01372	0.00696	0.02068	-145.85	-0.2967	0.14313	27
28	3.147	12.287	0.062	12.349	6.726	3.377	10.103	0.01421	0.00728	0.02149	-145.36	-0.2957	0.14996	28
29	3.297	12.312	0.065	12.377	6.966	3.540	10.506	0.01470	0.00761	0.02231	-144.86	-0.2947	0.15709	29
30	3.454	12.338	0.068	12.406	7.206	3.709	10.915	0.01519	0.00796	0.02315	-144.36	-0.2936	0.16452	30
31	3.617	12.363	0.071	12.434	7.446	3.887	11.333	0.01568	0.00832	0.02400	-143.86	-0.2926	0.17227	31
32	3.788	12.388	0.075	12.463	7.686	4.072	11.758	0.01617	0.00870	0.02487	-143.36	-0.2916	0.18035	32
33	3.788	12.388	0.075	12.463	7.686	4.072	11.758	0.01617	0.00870	0.02487	0.04	0.0000	0.18037	32
34	3.944	12.413	0.079	12.492	7.927	4.242	12.169	0.01666	0.00904	0.02570	1.05	0.0020	0.18778	33
35	4.107	12.438	0.082	12.520	8.167	4.418	12.585	0.01715	0.00940	0.02655	2.06	0.0041	0.19546	34
36	4.275	12.464	0.085	12.549	8.407	4.601	13.008	0.01764	0.00977	0.02741	3.06	0.0061	0.20342	35
37	4.450	12.489	0.089	12.578	8.647	4.791	13.438	0.01812	0.01016	0.02828	4.07	0.0081	0.21166	36
38	4.631	12.514	0.093	12.607	8.887	4.987	13.874	0.01861	0.01056	0.02917	5.07	0.0102	0.22020	37
39	4.818	12.540	0.097	12.637	9.128	5.191	14.319	0.01909	0.01097	0.03006	6.08	0.0122	0.22904	38
40	5.012	12.565	0.101	12.666	9.368	5.403	14.771	0.01957	0.01139	0.03096	7.08	0.0142	0.23819	39
41	5.213	12.590	0.105	12.695	9.608	5.622	15.230	0.02005	0.01183	0.03188	8.09	0.0162	0.24767	40
42	5.421	12.616	0.109	12.725	9.848	5.849	15.697	0.02053	0.01228	0.03281	9.09	0.0182	0.25748	41
43	5.638	12.641	0.114	12.755	10.088	6.084	16.172	0.02101	0.01275	0.03376	10.09	0.0202	0.26763	42
44	5.860	12.666	0.119	12.785	10.329	6.328	16.657	0.02149	0.01323	0.03472	11.10	0.0222	0.27813	43
45	6.091	12.691	0.124	12.815	10.569	6.580	17.149	0.02197	0.01373	0.03570	12.10	0.0242	0.28899	44
46	6.331	12.717	0.129	12.846	10.809	6.841	17.650	0.02245	0.01425	0.03670	13.10	0.0262	0.30023	45
47	6.578	12.742	0.134	12.876	11.049	7.112	18.161	0.02293	0.01478	0.03771	14.10	0.0282	0.31185	46
48	6.835	12.767	0.140	12.907	11.289	7.391	18.680	0.02340	0.01534	0.03874	15.11	0.0302	0.32386	47
49	7.100	12.792	0.146	12.938	11.530	7.681	19.211	0.02387	0.01591	0.03978	16.11	0.0321	0.33629	48
50	7.374	12.818	0.151	12.969	11.770	7.981	19.751	0.02434	0.01650	0.04084	17.11	0.0341	0.34913	49
51	0.7658	12.843	0.158	13.001	12.010	8.291	20.301	0.02481	0.01711	0.04192	18.11	0.0361	0.36240	50
52	0.7952	12.868	0.164	13.032	12.250	8.612	20.862	0.02528	0.01774	0.04302	19.11	0.0381	0.37611	51
53	0.8256	12.894	0.170	13.064	12.491	8.945	21.436	0.02575	0.01839	0.04414	20.11	0.0400	0.39028	52
54	0.8569	12.919	0.178	13.097	12.731	9.289	22.020	0.02622	0.01906	0.04528	21.12	0.0420	0.40492	53
55	0.8894	12.944	0.185	13.129	12.971	9.644	22.615	0.02669	0.01976	0.04645	22.12	0.0439	0.42004	54
56	0.9229	12.970	0.192	13.162	13.211	10.01	23.22	0.02716	0.02047	0.04763	23.12	0.0459	0.43565	55
57	0.9575	12.995	0.200	13.195	13.452	10.39	23.84	0.02762	0.02121	0.04883	24.12	0.0478	0.45176	56
58	0.9934	13.020	0.208	13.228	13.692	10.79	24.48	0.02809	0.02197	0.05006	25.12	0.0497	0.46840	57
59	1.030	13.045	0.216	13.261	13.932	11.19	25.12	0.02855	0.02276	0.05131	26.12	0.0517	0.48558	58
60	1.067	13.071	0.224	13.295	14.172	11.61	25.78	0.02902	0.02357	0.05259	27.12	0.0536	0.50330	59
61	1.108	13.096	0.233	13.329	14.413	12.05	26.46	0.02948	0.02441	0.05389	28.12	0.0555	0.52159	60
62	1.147	13.121	0.242	13.363	14.653	12.50	27.15	0.02994	0.02527	0.05521	29.12	0.0574	0.54047	61
63	1.191	13.147	0.251	13.398	14.893	12.96	27.85	0.03040	0.02616	0.05656	30.12	0.0594	0.55994	62
64	1.235	13.172	0.261	13.433	15.134	13.44	28.57	0.03086	0.02708	0.05794	31.12	0.0613	0.58002	63
65	1.280	13.197	0.271	13.468	15.374	13.94	29.31	0.03132	0.02803	0.05935	32.12	0.0632	0.60073	64
66	1.326	13.222	0.282	13.504	15.614	14.45	30.06	0.03177	0.02901	0.06078	33.11	0.0651	0.62209	65
67	1.374	13.247	0.292	13.539	15.855	14.98	30.83	0.03223	0.03002	0.06225	34.11	0.0670	0.64411	66
68	1.424	13.273	0.303	13.576	16.095	15.53	31.62	0.03269	0.03106	0.06375	35.11	0.0689	0.66681	67
69	1.475	13.298	0.315	13.613	16.335	16.09	32.42	0.03314	0.03213	0.06527	36.11	0.0708	0.69019	68
70	1.528	13.323	0.327	13.650	16.576	16.67	33.25	0.03360	0.03323	0.06683	37.11	0.0727	0.71430	69
71	1.582	13.348	0.339	13.687	16.816	17.27	34.09	0.03405	0.03437	0.06842	38.11	0.0746	0.73915	70
72	1.639	13.373	0.351	13.724	17.056	17.89	34.95	0.03450	0.03554	0.07004	39.11	0.0765	0.76475	71
73	1.697	13.398	0.364	13.762	17.297	18.53	35.82	0.03495	0.03675	0.07170	40.11	0.0784	0.79112	72
74	1.757	13.424	0.377	13.801	17.537	19.20	36.74	0.03540	0.03800	0.07340	41.11	0.0803	0.81828	73
75	1.819	13.449	0.392	13.841	17.778	19.88	37.66	0.03585	0.03928	0.07513	42.10	0.0821	0.84624	74
76	1.882	13.474	0.407	13.881	18.018	20.59	38.61	0.03630	0.04060	0.07690	43.10	0.0840	0.87504	75
77	1.948	13.499	0.422	13.921	18.259	21.31	39.57	0.03675	0.04197	0.07872	44.10	0.0859	0.90470	76
78	2.016	13.525	0.437	13.962	18.499	22.07	40.57	0.03720	0.04337	0.08057	45.10	0.0878	0.93523	77
79	2.086	13.550	0.453	14.003	18.740	22.84	41.58	0.03765	0.04482	0.08247	46.10	0.0896	0.96665	78
80	2.158	13.575	0.470	14.045	18.980	23.64	42.62	0.03810	0.04631	0.08441	47.10	0.0914	0.99899	79

Table 4—Thermodynamic Properties of Moist Air (Standard Atmospheric Pressure, 29.921 in. Hg)

Table 4—Thermodynamic Properties of Moist Air (Standard Atmospheric Pressure, 29.921 in. Hg)

Temp. °F	Humidity Ratio $W_s \times 10^2$	Volume cu ft/lb dry air v_a	v_{as}	v_s	Enthalpy Btu/lb dry air h_a	h_{as}	h_s	Entropy Btu/°F lb dry air s_a	s_{as}	s_s	Condensed Water Enthalpy Btu/lb h'_w	Entropy Btu/lb°F s'_w	Vap. Press. in. Hg p_s	Temp. °F
80	2.233	13.601	0.486	14.087	19.221	24.47	43.69	0.03854	0.04784	0.08638	48.10	0.0933	1.0323	80
81	2.310	13.626	0.504	14.130	19.461	25.32	44.78	0.03899	0.04942	0.08841	49.09	0.0952	1.0665	81
82	2.389	13.651	0.523	14.174	19.702	26.20	45.90	0.03943	0.05105	0.09048	50.09	0.0970	1.1017	82
83	2.471	13.676	0.542	14.218	19.942	27.10	47.04	0.03987	0.05273	0.09260	51.09	0.0989	1.1379	83
84	2.555	13.702	0.560	14.262	20.183	28.04	48.22	0.04031	0.05446	0.09477	52.09	0.1007	1.1752	84
85	2.642	13.727	0.581	14.308	20.423	29.01	49.43	0.04075	0.05624	0.09699	53.09	0.1025	1.2135	85
86	2.731	13.752	0.602	14.354	20.663	30.00	50.66	0.04119	0.05807	0.09926	54.08	0.1043	1.2529	86
87	2.824	13.777	0.624	14.401	20.904	31.03	51.93	0.04163	0.05995	0.10158	55.08	0.1062	1.2934	87
88	2.919	13.803	0.645	14.448	21.144	32.09	53.23	0.04207	0.06189	0.10396	56.08	0.1080	1.3351	88
89	3.017	13.828	0.668	14.496	21.385	33.18	54.56	0.04251	0.06389	0.10640	57.08	0.1098	1.3779	89
90	3.118	13.853	0.692	14.545	21.625	34.31	55.93	0.04295	0.06596	0.10890	58.08	0.1116	1.4219	90
91	3.223	13.879	0.716	14.595	21.865	35.47	57.33	0.04339	0.06807	0.11146	59.07	0.1135	1.4671	91
92	3.330	13.904	0.741	14.645	22.106	36.67	58.78	0.04382	0.07025	0.11407	60.07	0.1153	1.5135	92
93	3.441	13.929	0.768	14.697	22.346	37.90	60.25	0.04426	0.07249	0.11675	61.07	0.1171	1.5612	93
94	3.556	13.954	0.795	14.749	22.587	39.18	61.77	0.04469	0.07480	0.11949	62.07	0.1188	1.6102	94
95	3.673	13.980	0.822	14.802	22.827	40.49	63.32	0.04513	0.07718	0.12231	63.07	0.1206	1.6606	95
96	3.795	14.005	0.851	14.856	23.068	41.85	64.92	0.04556	0.07963	0.12519	64.06	0.1224	1.7123	96
97	3.920	14.030	0.881	14.911	23.308	43.24	66.55	0.04600	0.08215	0.12815	65.06	0.1242	1.7654	97
98	4.049	14.056	0.911	14.967	23.548	44.68	68.23	0.04643	0.08474	0.13117	66.06	0.1260	1.8199	98
99	4.182	14.081	0.942	15.023	23.789	46.17	69.96	0.04686	0.08741	0.13427	67.06	0.1278	1.8759	99
100	4.319	14.106	0.975	15.081	24.029	47.70	71.73	0.04729	0.09016	0.13745	68.06	0.1296	1.9333	100
101	4.460	14.131	1.009	15.140	24.270	49.28	73.55	0.04772	0.09299	0.14071	69.05	0.1314	1.9923	101
102	4.606	14.157	1.043	15.200	24.510	50.91	75.42	0.04815	0.09591	0.14406	70.05	0.1332	2.0528	102
103	4.756	14.182	1.079	15.261	24.751	52.59	77.34	0.04858	0.09891	0.14749	71.05	0.1350	2.1149	103
104	4.911	14.207	1.117	15.324	24.991	54.32	79.31	0.04900	0.1020	0.1510	72.05	0.1367	2.1786	104
105	5.070	14.232	1.155	15.387	25.232	56.11	81.34	0.04943	0.1052	0.1546	73.04	0.1385	2.2439	105
106	5.234	14.258	1.194	15.452	25.472	57.95	83.42	0.04985	0.1085	0.1584	74.04	0.1403	2.3109	106
107	5.404	14.283	1.235	15.518	25.713	59.85	85.56	0.05028	0.1118	0.1621	75.04	0.1421	2.3797	107
108	5.578	14.308	1.278	15.586	25.953	61.80	87.76	0.05070	0.1153	0.1660	76.04	0.1438	2.4502	108
109	5.758	14.333	1.321	15.654	26.194	63.82	90.03	0.05113	0.1189	0.1700	77.04	0.1456	2.5225	109
110	0.5944	14.359	1.365	15.724	26.434	65.91	92.34	0.05155	0.1226	0.1742	78.03	0.1472	2.5966	110
111	0.6135	14.384	1.412	15.796	26.675	68.05	94.72	0.05197	0.1264	0.1784	79.03	0.1491	2.6726	111
112	0.6333	14.409	1.460	15.869	26.915	70.27	97.18	0.05239	0.1302	0.1826	80.03	0.1508	2.7505	112
113	0.6536	14.435	1.509	15.944	27.156	72.55	99.71	0.05281	0.1342	0.1870	81.03	0.1525	2.8304	113
114	0.6746	14.460	1.560	16.020	27.397	74.91	102.31	0.05323	0.1384	0.1916	82.03	0.1543	2.9123	114
115	0.6962	14.485	1.613	16.098	27.637	77.34	104.98	0.05365	0.1426	0.1963	83.02	0.1560	2.9962	115
116	0.7185	14.510	1.668	16.178	27.878	79.85	107.73	0.05407	0.1470	0.2011	84.02	0.1577	3.0821	116
117	0.7415	14.536	1.723	16.259	28.119	82.43	110.55	0.05449	0.1515	0.2060	85.02	0.1595	3.1701	117
118	0.7652	14.561	1.782	16.343	28.359	85.10	113.46	0.05490	0.1562	0.2111	86.02	0.1612	3.2603	118
119	0.7897	14.586	1.842	16.428	28.600	87.86	116.46	0.05532	0.1610	0.2163	87.02	0.1629	3.3527	119
120	0.8149	14.611	1.905	16.516	28.841	90.70	119.54	0.05573	0.1659	0.2216	88.01	0.1646	3.4474	120
121	0.8410	14.637	1.968	16.605	29.082	93.64	122.72	0.05615	0.1710	0.2272	89.01	0.1664	3.5443	121
122	0.8678	14.662	2.034	16.696	29.322	96.66	125.98	0.05656	0.1763	0.2329	90.01	0.1681	3.6436	122
123	0.8955	14.687	2.103	16.790	29.563	99.79	129.35	0.05698	0.1817	0.2387	91.01	0.1698	3.7452	123
124	0.9242	14.712	2.174	16.886	29.804	103.0	132.8	0.05739	0.1872	0.2446	92.01	0.1715	3.8493	124
125	0.9537	14.738	2.247	16.985	30.044	106.4	136.4	0.05780	0.1930	0.2508	93.01	0.1732	3.9558	125
126	0.9841	14.763	2.323	17.086	30.285	109.8	140.1	0.05821	0.1989	0.2571	94.01	0.1749	4.0649	126
127	1.016	14.788	2.401	17.189	30.526	113.4	143.9	0.05862	0.2050	0.2636	95.00	0.1766	4.1765	127
128	1.048	14.813	2.482	17.295	30.766	117.0	147.8	0.05903	0.2113	0.2703	96.00	0.1783	4.2907	128
129	1.082	14.839	2.565	17.404	31.007	120.8	151.8	0.05944	0.2178	0.2772	97.00	0.1800	4.4076	129
130	1.116	14.864	2.652	17.516	31.248	124.7	155.9	0.05985	0.2245	0.2844	98.00	0.1817	4.5272	130
131	1.152	14.889	2.742	17.631	31.489	128.8	160.3	0.06026	0.2314	0.2917	99.00	0.1834	4.6495	131
132	1.189	14.915	2.834	17.749	31.729	133.0	164.7	0.06067	0.2386	0.2993	100.00	0.1851	4.7747	132
133	1.227	14.940	2.930	17.870	31.970	137.3	169.3	0.06108	0.2459	0.3070	101.00	0.1868	4.9028	133
134	1.267	14.965	3.029	17.994	32.211	141.8	174.0	0.06148	0.2536	0.3151	102.00	0.1885	5.0337	134
135	1.308	14.990	3.132	18.122	32.452	146.4	178.9	0.06189	0.2614	0.3233	103.00	0.1902	5.1676	135
136	1.350	15.016	3.237	18.253	32.692	151.2	183.9	0.06229	0.2695	0.3318	104.00	0.1918	5.3046	136
137	1.393	15.041	3.348	18.389	32.933	156.1	189.0	0.06270	0.2778	0.3405	105.00	0.1935	5.4446	137
138	1.439	15.066	3.462	18.528	33.174	161.2	194.4	0.06310	0.2865	0.3496	106.00	0.1952	5.5878	138
139	1.485	15.091	3.580	18.671	33.414	166.5	199.9	0.06350	0.2954	0.3589	107.00	0.1969	5.7342	139
140	0.1534	15.117	3.702	18.819	33.655	172.0	205.7	0.06390	0.3047	0.3686	107.99	0.1985	5.8838	140
141	0.1584	15.142	3.829	18.971	33.896	177.7	211.6	0.06430	0.3142	0.3785	108.99	0.2002	6.0367	141
142	0.1636	15.167	3.961	19.128	34.136	183.6	217.7	0.06470	0.3241	0.3888	109.99	0.2018	6.1930	142
143	0.1689	15.192	4.098	19.290	34.377	189.7	224.1	0.06511	0.3343	0.3994	110.99	0.2035	6.3527	143
144	0.1745	15.218	4.239	19.457	34.618	196.0	230.6	0.06549	0.3449	0.4104	111.99	0.2051	6.5160	144
145	0.1803	15.243	4.386	19.629	34.859	202.5	237.4	0.06589	0.3559	0.4218	112.99	0.2068	6.6828	145
146	0.1862	15.268	4.539	19.807	35.099	209.3	244.4	0.06629	0.3672	0.4335	113.99	0.2084	6.8532	146
147	0.1924	15.293	4.698	19.991	35.340	216.4	251.7	0.06669	0.3790	0.4457	114.99	0.2101	7.0273	147
148	0.1989	15.319	4.862	20.181	35.581	223.7	259.3	0.06708	0.3912	0.4583	115.99	0.2117	7.2051	148
149	0.2055	15.344	5.033	20.377	35.822	231.3	267.1	0.06748	0.4038	0.4713	116.99	0.2134	7.3867	149
150	0.2125	15.369	5.211	20.580	36.063	239.2	275.3	0.06787	0.4169	0.4848	117.99	0.2150	7.5722	150
151	0.2197	15.394	5.396	20.790	36.304	247.3	283.6	0.06827	0.4304	0.4987	118.99	0.2167	7.7616	151
152	0.2271	15.420	5.587	21.007	36.545	255.9	292.4	0.06866	0.4445	0.5132	119.99	0.2183	7.9550	152
153	0.2349	15.445	5.788	21.233	36.785	264.7	301.5	0.06906	0.4591	0.5282	120.99	0.2200	8.1525	153
154	0.2430	15.470	5.998	21.466	37.026	273.9	310.9	0.06945	0.4743	0.5438	121.99	0.2216	8.3541	154
155	0.2514	15.496	6.213	21.709	37.267	283.5	320.8	0.06984	0.4901	0.5599	122.99	0.2232	8.5599	155
156	0.2602	15.521	6.439	21.960	37.508	293.5	331.0	0.07023	0.5066	0.5768	123.99	0.2248	8.7701	156
157	0.2693	15.546	6.675	22.221	37.749	303.9	341.7	0.07062	0.5237	0.5943	124.99	0.2265	8.9846	157
158	0.2788	15.571	6.922	22.493	37.990	314.7	352.7	0.07101	0.5415	0.6125	125.99	0.2281	9.2036	158
159	0.2887	15.597	7.178	22.775	38.231	326.0	364.2	0.07140	0.5600	0.6314	127.00	0.2297	9.4271	159
160	0.2990	15.622	7.446	23.068	38.472	337.8	376.3	0.07179	0.5793	0.6511	128.00	0.2313	9.6552	160
161	0.3098	15.647	7.727	23.374	38.713	350.1	388.8	0.07218	0.5994	0.6716	129.00	0.2329	9.8878	161
162	0.3211	15.672	8.020	23.692	38.954	363.0	402.0	0.07257	0.6204	0.6930	130.00	0.2345	10.125	162
163	0.3329	15.698	8.326	24.024	39.195	376.5	415.7	0.07296	0.6423	0.7153	131.00	0.2361	10.367	163
164	0.3452	15.723	8.648	24.371	39.436	390.5	429.9	0.07334	0.6652	0.7385	132.00	0.2377	10.614	164
165	0.3581	15.748	8.985	24.733	39.677	405.3	445.0	0.07373	0.6892	0.7629	133.00	0.2393	10.866	165
166	0.3716	15.773	9.339	25.112	39.918	420.8	460.7	0.07411	0.7142	0.7883	134.00	0.2409	11.123	166
167	0.3858	15.799	9.708	25.507	40.159	437.0	477.2	0.07450	0.7405	0.8150	135.01	0.2426	11.385	167
168	0.4007	15.824	10.098	25.922	40.400	454.0	494.4	0.07488	0.7680	0.8429	136.01	0.2441	11.652	168
169	0.4163	15.849	10.508	26.357	40.641	471.8	512.4	0.07527	0.7969	0.8722	137.01	0.2457	11.925	169
170	0.4327	15.874	10.934	26.812	40.882	490.6	531.5	0.07565	0.8273	0.9030	138.01	0.2473	12.203	170
171	0.4500	15.900	11.391	27.291	41.123	510.4	551.5	0.07603	0.8592	0.9352	139.01	0.2489	12.486	171
172	0.4682	15.925	11.870	27.795	41.364	531.3	572.7	0.07641	0.8927	0.9691	140.01	0.2505	12.775	172
173	0.4875	15.950	12.376	28.326	41.605	553.3	594.9	0.07680	0.9281	1.0046	141.01	0.2521	13.069	173
174	0.5078	15.975	12.911	28.886	41.846	576.5	618.3	0.07718	0.9654	1.0420	142.02	0.2537	13.369	174
175	0.5292	16.001	13.475	29.476	42.087	601.1	643.2	0.07756	1.005	1.083	143.02	0.2553	13.675	175
176	0.5519	16.026	14.074	30.100	42.328	627.1	669.4	0.07794	1.047	1.125	144.02	0.2568	13.987	176
177	0.5760	16.051	14.710	30.761	42.569	654.7	697.3	0.07832	1.091	1.169	145.02	0.2584	14.304	177
178	0.6016	16.076	15.386	31.462	42.810	684.1	726.9	0.07870	1.137	1.216	146.03	0.2600	14.629	178
179	0.6288	16.102	16.104	32.206	43.051	715.2	758.3	0.07908	1.187	1.266	147.03	0.2616	14.958	179
180	0.6578	16.127	16.870	32.997	43.292	748.5	791.8	0.07946	1.240	1.319	148.03	0.2631	15.294	180
181	0.6887	16.152	17.679	33.841	43.534	783.9	827.4	0.07984	1.296	1.374	149.03	0.2647	15.636	181
182	0.7218	16.177	18.536	34.742	43.775	821.9	865.7	0.08021	1.357	1.437	150.04	0.2662	15.985	182
183	0.7572	16.203	19.504	35.707	44.016	862.5	906.5	0.08059	1.421	1.502	151.04	0.2678	16.340	183
184	0.7953	16.228	20.513	36.741	44.257	906.2	950.5	0.08096	1.490	1.571	152.04	0.2693	16.702	184
185	0.8363	16.253	21.601	37.854	44.498	953.2	997.7	0.08134	1.565	1.646	153.05	0.2709	17.071	185
186	0.8805	16.279	22.775	39.053	44.740	1004	1049	0.08171	1.645	1.727	154.05	0.2724	17.446	186
187	0.9283	16.304	24.047	40.351	44.981	1059	1104	0.08208	1.731	1.813	155.05	0.2740	17.828	187
188	0.9802	16.329	25.427	41.756	45.222	1119	1164	0.08245	1.825	1.907	156.06	0.2755	18.217	188
189	1.037	16.354	26.934	43.288	45.463	1184	1229	0.08283	1.929	2.011	157.06	0.2771	18.614	189
190	1.099	16.379	28.580	44.959	45.704	1255	1301	0.08320	2.039	2.122	158.07	0.2786	19.017	190
191	1.166	16.405	30.385	46.790	45.946	1332	1378	0.08357	2.161	2.245	159.07	0.2802	19.427	191
192	1.241	16.430	32.375	48.805	46.187	1418	1464	0.08394	2.296	2.380	160.07	0.2817	19.845	192
193	1.324	16.455	34.581	51.036	46.428	1513	1559	0.08431	2.444	2.528	161.08	0.2833	20.271	193
194	1.416	16.480	37.036	53.516	46.670	1619	1666	0.08468	2.609	2.694	162.08	0.2848	20.704	194
195	1.519	16.506	39.785	56.291	46.911	1737	1784	0.08505	2.794	2.879	163.09	0.2864	21.145	195
196	1.635	16.531	42.885	59.416	47.153	1871	1918	0.08542	3.002	3.087	164.09	0.2879	21.594	196
197	1.767	16.556	46.402	62.958	47.394	2022	2069	0.08579	3.238	3.324	165.10	0.2895	22.050	197
198	1.917	16.581	50.426	67.007	47.636	2195	2243	0.08616	3.507	3.593	166.10	0.2910	22.514	198
199	2.091	16.607	55.074	71.681	47.877	2395	2443	0.08653	3.817	3.904	167.11	0.2925	22.987	199
200	2.295	16.632	60.510	77.142	48.119	2629	2677	0.08689	4.179	4.266	168.11	0.2940	23.468	200

shows the two assumed laws of force. Fig. 4 shows the values of A_{aw} calculated from the improved law, and it is felt that they deserve considerable confidence, especially since they are obtained by the adjustment of only one constant in a theory which has already registered many successes. We have formulated these values of A_{aw} into the following empirical equation:

$$A_{aw} = -0.4730 + 5.950 \times 10^{-5}\, T\,(1 - e^{-\frac{7640.7}{T}}) + \frac{505.91}{T} + \frac{4949}{T^2} + \frac{7.957 \times 10^6}{T^3}\ (\text{ft}^3/\text{mol}) \quad \ldots\ldots\ldots\ldots\ 16.2$$

where T is °*R*.

The bold extrapolation represented in Fig. 4 requires additional discussion. In the first place, some sort of extrapolation is necessary because, during war conditions, it became impossible to extend the range of experimental values beyond what had already been covered. That the particular method used deserves considerable confidence is chiefly because it involves the adjustment of only one constant in a well-tested theory. It is true, of course, that the theory involves several approximations so that the possibility that the extrapolated values of A_{aa} may differ appreciably from the true values cannot be denied. Still the effect of A_{aw} on the various properties of moist air happens to be greatest right in the experimental range and is almost negligible at both extremes of the extrapolated range. Thus, while the estimated uncertainty of 5 per cent in A_{aw} at 68 F produces an uncertainty of 0.015 per cent in the humidity ratio W_s of saturated moist air (at atmospheric pressure), the same uncertainty in W_s at 192 F would require an uncertainty of 70 per cent in A_{aw} there. Also, while the effect of A_{aw} on W_s is greater at the very low temperatures, its effect on the other thermodynamic properties is negligible because W_s is itself so very small. Thus an error of 20 per cent in A_{aw} at —160 F produces an error of 0.3 per cent in W_s, but of only 0.00000001 Btu/lb dry air in h_s, the enthalpy of saturated moist air (at atmospheric pressure); furthermore, an uncertainty 0.3 per cent in W_s is less than that produced by the present uncertainty of the vapor pressure data at —160 F.

IV. Table 4

The first item to be entered in Table 4, Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, is the vapor pressure p_s. For temperatures below and at 32 F, the values listed are those for equilibrium over ice recalculated as explained in §10. Strictly speaking, these should be extended upward to 32.0176 F, the triple point where solid, liquid, and vapor phases coexist. There is a double entry at 32 F, the second representing an extrapolated value of the vapor pressure of saturated liquid. This and values at the higher temperatures have been computed from the integral of (9.1). All vapor pressure data have been converted to inches of mercury by means of the conversion factor 29.921 inches Hg/atm.

The next items entered in Table 4 are the specific enthalpy h_w' and specific entropy s_w' of *pure water at standard atmospheric pressure*. These were obtained by applying suitable corrections to the corresponding values at saturation which were calculated in the manner explained in §6. The correction to the specific enthalpy is

$$\Delta h = \left[\frac{\partial (v\tau)}{\partial \tau}\right]_p (p - p_s) \quad \ldots\ldots 17.1$$

that to the specific entropy is given by

$$T\,\Delta s = \Delta h - v\,(p - p_s) \quad \ldots 17.2$$

and turns out to be entirely negligible. The decision to list values at standard atmospheric pressure rather than at saturation pressure has been based on consideration of the practical uses to which the table is most likely to be put. Thus, when moist air is cooled below the dew-point, liquid (or ice) condenses out under the observed or *total* pressure p. Strictly speaking, the condensed phase is not pure water but contains a small quantity of dissolved air which affects its enthalpy and entropy slightly; however, corrections for this effect have not been applied.

The next item entered in the table is the humidity ratio at saturation W_s. The corresponding mol fraction of dry air x_s is computed directly from (14.6) and then converted to humidity ratio by the definition,

$$W_s = 18.0154\,(1 - x_s)/28.966\,x_s \quad \ldots 17.3$$

The specific volume v_a, specific enthalpy h_a, and specific entropy s_a of dry air are computed from (2.0), (3.0), (3.1), respectively, using (2.4) for numerical values of the second virial coefficient A_{aa} and its derivatives B_{aa} and C_{aa} and completely ignoring the third virial coefficient A_{aaa}. That (2.4) is sufficiently accurate to stand the differentiations necessary to obtain values of B_{aa} and C_{aa} from it has been tested by Bridgeman,[5] using Joule-Thomson and other calorimetric data for comparison. The

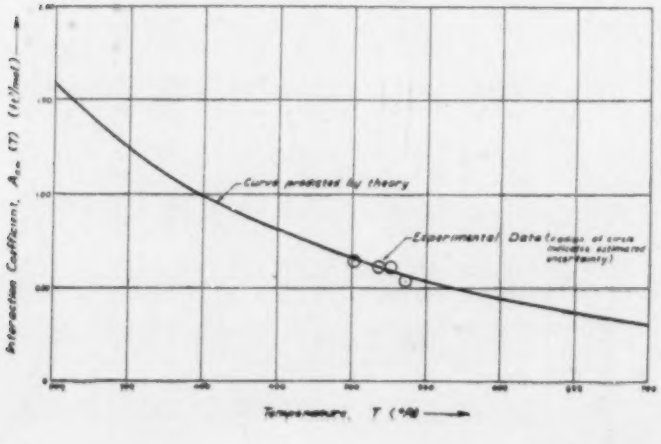

Fig. 4—Extrapolation of experimental data on interaction coefficient

method of obtaining zero-pressure enthalpies and reduced entropies has been explained in §3.

The saturation volume v_s, saturation enthalpy h_s, and saturation entropy s_s are computed from (13.8), (13.9), (13.10), respectively, using for mol fraction $1-x_s$ the values computed from (14.6) and dividing by 28.966 x_s in order to refer to unit weight of dry air. The determination of the various temperature functions appearing in these equations has been explained in considerable detail.

The humidity ratio W, that is the weight of water vapor per unit weight of dry air, may have any value between zero and W_s, the humidity ratio at saturation. The ratio $\mu = W/W_s$, called *degree of saturation* or *per cent saturation*, may therefore have any value between zero and unity. As a close approximation the corresponding values of volume v, enthalpy h, and entropy s, may be computed from the linear equations,

$$\left.\begin{aligned} v &= v_a + \mu(v_s - v_a) \\ h &= h_a + \mu(h_s - h_a) \\ s &= s_a + \mu(s_s - s_a) \end{aligned}\right\} \quad \ldots\ldots 17.4$$

To facilitate such computations, the differences appearing in parentheses in (17.4) have been included in Table 6 under the headings v_{as}, h_{as}, and s_{as}, respectively.

The use of linear interpolation according to (17.4) involves some loss of accuracy, especially at the higher temperatures, but hardly enough to justify complicating the tables to regain it. When it comes to representing Table 4 in the form of a Mollier Chart, the actual isotherm curvature can be incorporated without introducing complications except in the actual drawing of the chart.

V. Conclusion

From the discussion of preceding sections it is clear that there is still room for improvement in the primary data which constitute the ingredients of the present formulation. This is especially true of the virial and interaction coefficients. Also there is much room for improvement in the theory by which these primary data are put together as suggested by the arbitrary manner in which the third virial coefficients have been handled.

In spite of the above shortcomings we believe that the present formulation is more than sufficiently accurate for all practical purposes now and in the near future. All available data have been represented well within their respective accuracies and only in a few instances have possible refinements been neglected. For example, to repeat the state-sum calculation of the zero-pressure properties using the newest and best spectroscopic data would improve their accuracy somewhat, but such improvement would not be noticed in the final formulation because of irreducible inaccuracies in other data used.

The only part of the present formulation which is offered with reservations other than those with which any numerical computations must be offered is the part at higher temperatures, say above 150 F. Here it has been necessary to exercise arbitrariness in handling the third virial and corresponding interaction coefficients, and it may be that some error has been introduced. However, without further information, both experimental and theoretical, the authors know of no better procedure to follow. To remove this and other sources of uncertainty would probably require an elaborate research program similar to the steam research program of the past two decades. But it is to be doubted that such additional experimentation is warranted by actual needs, at any rate, now and for some time to come.

Although Table 4 is for standard atmospheric pressure only, the necessary information is at hand for the preparation of similar tables for other pressures. Accurate tables can be prepared for fairly high pressures if there is a real need for them, though as pressure increases the effects of the third virial coefficient become more pronounced. At any rate, suggestions regarding needs for tables at other pressures are invited.

Acknowledgment

It is gratifying to note that the Council of the American Society of Heating and Ventilating Engineers has recently agreed to sponsor the formation of an inter-society committee to attempt to reach agreement on a standard table of properties to be recommended for general adoption.

The authors have derived a great amount of pleasure from the moist air research reported herein and for the opportunity to engage in it wish to thank the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, who have generously supported the program. It is also a pleasure to acknowledge indebtedness to Dr. A. C. Bates, formerly Assistant Professor in Mechanical Engineering, University of Pennsylvania, and J. R. Andersen, Instructor in Mechanical Engineering, University of Pennsylvania, for their contributions, both experimental and analytical. Dr. H. Margenau, Sloane Laboratory of Physics, Yale University, has given generously of advice and guidance in the use of modern physical theory in the analytical part of the investigation. A special fund for research in Mechanical Engineering provided by Col. E. M. Chance, President, United Engineers and Constructors, has made possible the purchase of a modern electric calculator, without which the labor involved in necessary routine calculations would have been greatly increased.

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DISCUSSION

W. L. Fleisher, New York, N. Y., expressed the opinion that the paper represented the first fundamental research work done by the Society and that it would tend to establish ASHVE as a scientific organization. He felt that the Society owed a great debt of gratitude to Dean Goff for making this contribution to scientific knowledge through the ASHVE.

John James, Cleveland, Ohio, expressed an opinion that Dean Goff's work would be recognized in the scientific world just as steam tables are at present. He expressed the hope that improved instruments for the accurate determination of psychrometric conditions within an enclosure would become available for use with the improved data on properties of moist air. Mr. James also expressed appreciation of the work done by Dean Goff.

Mr. Tasker spoke of the Society's appreciation of Dean Goff and referred to the important work before the Technical Advisory Committee on Psychrometry, which had the project of improving instrumentation to equal the accuracy of the psychrometric data presented by Dean Goff. Some progress, he said, had been made in the preliminary report on present methods of measuring the properties of mixtures of air and water vapor prepared by the Research Laboratory. It was expected that experimental work on instrumentation for determining the true dew point would follow. Those who might ask for and receive a copy of the Research Report were requested to examine it critically and send comments upon it to the Research Laboratory.

Mr. Fleisher asked whether Dean Goff could explain why the effect of the virial coefficient was sometimes positive and sometimes negative.

Professor Mackey expressed appreciation of the paper and made certain suggestions with the idea of obtaining a set of tables which might be adopted nationally. These suggestions were: (1) a more complete separation of the actual equations used in preparation of the tables from the justification for the formulas and the constants used in the equations; (2) a complete separation of the tables for dry air from those for moist air; (3) an extension of the method used in preparing the tables to atmospheric pressures other than 29.921 for both dry and moist air.

For instance, in referring to the properties of dry air the specific volume is 13.349 cu ft at 70 F at standard pressure and at 28.5 in. Hg the specific volume is 14.015. Specific volume is made up of the algebraic sum of two functions; one a pressure function and the other a temperature function. The second virial coefficient is the temperature function and if the sum is separated into two parts in the table only one part needs to be corrected for departures from standard pressure. That part can be corrected by multiplying or dividing by pressure ratios and then added algebraically to the second virial coefficient which is independent of pressure. If other properties such as enthalpy and entropy could be separated into individual constituents of temperature and pressure functions it would be a simple matter to correct the properties for that departure.

Professor Mackey mentioned the need for additional tables of properties of moist air to be used when the total pressure, dry-bulb temperature and thermodynamic wet-bulb are known, but the state is less than 100 per cent saturated.

Author's Closure: Dean Goff expressed appreciation of the favorable comments made and stated that the research problem originally proposed by the Society had led to many others all of which were interesting and led to improved concepts of thermodynamics.

Beginning at zero absolute pressure where knowledge was most accurate it has been possible to move to finite pressures on the basis of experimental knowledge at first and then later, because of developments in modern physics, by theoretical procedure.

In reply to Mr. Fleisher's inquiry, Dean Goff referred to Fig. 3 of his paper and stated that the forces of attraction and repulsion effective between a pair of molecules are purely electrostatic, each diatomic molecule consisting of two atoms arranged like a dumbbell separated a certain distance and having certain moments of inertia, each atom carrying a certain charge and having electrons moving around it, so that it creates and moves in an electro-static field.

The problem is to find out how the electrostatic potential of a pair of rotating molecules depends upon their mutual orientation and on their distance of separation. From that information through the methods of statistical mechanics it is possible to determine the average effect and compute or predict the various coefficients.

At high temperatures under rapid motion the molecules come frequently within close distance of each other and the law of force suddenly changes to one of repulsion and the repulsive forces give rise to the steep part of the curve and have the net effect on the virial coefficient of making it negative. The specific volume at any given pressure then exceeds the value expected on the basis of perfect gas laws.

At low temperatures under slow motion of the molecules the forces are predominantly attractive because the molecules are less frequently close to each other and as shown by the right hand portion of the curve, Fig. 3, the second virial coefficient is positive.

Dean Goff then considered the comments made by Professor Mackey. He was in agreement that a separate table on properties of dry air might be desirable although the table of properties of moist air presented in the paper included the data needed in the general problems of air and water mixtures.

Data are at hand for extending the table to higher and lower pressures, whenever an agreement can be reached on the most useful pressures to be listed.

Consideration should be given by the Technical Advisory Committee on Psychrometry, said Dean Goff, to Professor Mackey's suggestion of a table for zero pressure plus a series of tables for corrections at higher pressures.

Specific volume for an unsaturated mixture can be found from Table 4 by adding to the volume of dry air the product of the difference between the specific volume of dry and saturated air multiplied by the per cent saturation ÷ 100. The results obtained by such linear interpolation would be less than the uncertainty in the table below 100 F.

G. L. Tuve

TUVE HEADS M.E. DEPT. AT CASE

Prof. G. L. Tuve of Case School of Applied Science, Cleveland, O., has just been appointed head of the Department of Mechanical Engineering by Pres. W. E. Wickenden to succeed Prof. F. H. Vose, who has held the office for 31 years. Professor Tuve will start his new duties on July 1, after having served the Case faculty since 1930.

For the past two years Professor Tuve has been Chairman of the Committee on Research of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and has served on its Council for five years. Since joining the ASHVE in 1932 he has served on many of its Research Technical Advisory Committees, as a member of the Meetings, Standards and Guide Publication Committees, and he has contributed numerous papers which appear in the Society's TRANSACTIONS.

Professor Tuve has specialized in heating, ventilating, air conditioning, heat transmission and air flow since receiving his B.S. in Mechanical Engineering from Northwestern University in 1920, and his M.E. from the University of Minnesota in 1921. After a year in experimental work with the Mahr Mfg. Co., Minneapolis, he joined the staff of the University of Minnesota and then became Assistant Professor of Mechanical Engineering, University of Montana, and later Associate Professor, and Head of the Department of Mechanical Engineering at Texas Technological College, Lubbock, Tex.

He is co-author with Prof. C. F. Shoop of a textbook, Mechanical Engineering Laboratory Practice, which includes instruction for common test work encountered by heating and ventilating engineers.

NOMINATIONS INVITED

The Committee of Award for the F. Paul Anderson Medal will receive nominations until August 1, 1945.

The F. Paul Anderson Medal is awarded to a member of the ASHVE, "in recognition of notable scientific achievement or for outstanding service performed in the field of heating, ventilating or air conditioning."

Nominations should be addressed to the Committee of Award for the F. Paul Anderson Medal and should be accompanied by a detailed statement indicating the specific achievement or service performed.

The committee shall carefully consider nominations and will submit its recommendations to the Council at the final Council Meeting of the calendar year.

Under the regulations the Council has the power to decline to make any award for any year.

The undersigned Committee of Award for the F. Paul Anderson Medal invites members of the Society to submit nominations.

Alfred J. Offner, *Chairman*
W. H. Carrier
F. E. Giesecke
W. L. Fleisher
F. B. Rowley

REFRIGERATION AND AIR CONDITIONING ENGINEERING

Refrigeration and Air Conditioning Engineering is the title of a book by B. F. Raber, chairman, Division of Mechanical Engineering, and F. W. Hutchinson, member of ASHVE and Associate Professor of Mechanical Engineering, both of the University of California, Berkeley, Calif.

Chapter headings include: Thermodynamic Principles; Fundamental Cycles of Vapor Refrigeration Systems; Complex Compression Cycles for Single-Load System; Analysis of Actual Cycles; The Absorption Cycle; Steady State Heat Transfer; Periodic Heat Transfer; Transient Heat Flow; Psychrometric Principles; Supply State of Conditioned Air; Psychrometric Processes; Process Combinations; Design State and Design Volume; Ventilation Systems; Fan Performance and Selection; and Airway Design.

The aim of the authors is to give the engineer, designer and advanced student a sound background and a knowledge of the fundamental principles of the science of refrigeration and air conditioning.

Handbook data are not given in this book, since they are readily available elsewhere in detail. Instead, attention is concentrated upon rational *graphical* procedures for solving refrigeration and air conditioning problems. The general case, rather than the specific application, is used to demonstrate the theory. The material is based upon original and clear analysis and ample illustrative examples are given. Problems are grouped at the end of each chapter, as well as bibliographies for reference reading. Sixteen folding charts are included in a pocket on the inside back cover, for the convenience of the reader.

The following description of special features of the book indicates the method of approach in explaining the various processes and cycles and in obtaining simplified solutions by means of charts and trace sheets.

This book offers the following distinct aids:

1. Graphical solutions, wherever possible, for the more important rational equations: for polytropic processes; for dual-effect compression; for ventilation volume requirements; for the equivalent radiation coefficient; for duct friction losses; for duct fitting head losses.

2. Charts developed for use in rapidly selecting the most efficient fan for any given service.

3. The entire subject of refrigeration treated in terms of pictorial representation of both actual and ideal cycles, on the pressure-enthalpy chart.

4. A new method of graphically solving cycle problems by means of a superimposed trace sheet.

5. ph charts and trace sheets, in pairs, for eight of the most widely used refrigerants.

6. Methods for obtaining approximate graphical solutions of the influence of transient and periodic heat transfer on load determination, including detailed illustrative examples showing how the approximate methods described can be applied to practical

problems without the use of advanced mathematics.

7. A treatment of air-vapor processes and cycles in terms of the psychrometric chart — more particularly, for instance, a treatment of critical loading conditions, and the visualization of health as well as comfort zones on the psychrometric chart.

It is published by John Wiley & Sons, Inc., New York, N. Y. and is priced at $4.00 per copy.

1945 DOMESTIC ENGINEERING CATALOG DIRECTORY

The 1945 edition of the Domestic Engineering Catalog Directory includes buying and specifying information on the following products and equipment: Heating, Plumbing, Piping, Water Systems, Plumbers' Specials, Heating Specialties, Stokers, Oil Burners, Air Conditioning, Humidifying, Refrigerating, Insulating, Compressors, Fans, Blowers and Accessories.

The book is divided into five sections:

Manufacturers' Catalogs Section containing up-to-date buying and specifying information on heating, plumbing, piping, air conditioning and allied equipment and accessories now available under war-time restrictions and ratings.

Tables and Rules Section containing 159 pages of revised technical data consisting of standard tables, rules, charts and diagrams used in the heating, plumbing, piping and air conditioning industry. Of these 159 pages, 64 pages are devoted to charts and explanatory diagrams.

Trade Names Section including approximately 7500 trade names from which may be found the names and addresses of manufacturers of various products.

Classified Directory Section, in which there are approximately 900 name classifications and headings under which are listed the names and locations of manufacturers of various products.

Name and Address Section including approximately 3350 manufacturers (with street address) who make items used in the heating, plumbing, piping and air conditioning industries.

The Directory is published by Domestic Engineering Co., 1900 Prairie Ave., Chicago 16, Ill.

NEW HIGH-SPEED, HIGH-ALTITUDE WIND TUNNEL ANNOUNCED

A new $2,500,000 variable density wind tunnel, capable of testing airplanes in the *fast-as-sound range*, is practically ready for operation at the Curtiss-Wright Corp. plant in Buffalo, N. Y.

The tunnel will be capable of testing airplanes at pressure conditions comparable to those found at 35,000 ft. It contains an air volume of 210,000 cu ft, equal to the cubic air volume contained within 16 six-room houses. California Institute of Technology used the same basic design in construction of its new tunnel at Pasadena, Calif., just recently announced.

The new tunnel will serve not only as a Curtiss *proving ground* but it will also be in a position to serve as a testing laboratory for other eastern airplane manufacturers.

The mammoth tunnel's extreme flexibility of *testing range* makes it possible to test models of all types of planes, thus accomplishing in less time and in one place, work which previously had been performed by three or four tunnels.

The big tunnel of 378 ft circuit length has an 8½x12 ft test chamber which permits testing a model of 10-ft span. Over-all length of the tunnel is 178 ft. Its over-all width is 81 ft. Steel used in the tunnel's construction is equal to that employed in the construction of a heavy U. S. Navy destroyer. The tunnel stands 36 ft from the ground at its maximum height.

The 115,000-volt power supply for the tunnel is brought into the plant through a 10,000 kilovolt-ampere outdoor substation where it is reduced to 4800 volts for use with the 14,000 hp drive motors. This power service is adequate for the tunnel to operate, if need be, 24 hours a day, with good voltage regulation, an advantage enjoyed by few wind tunnels in the United States.

By means of four special compressors, air pressure in the three-quarter inch steel shell may be increased to 60 lb per square inch.

On the other end of the *pressure range* the tunnel may be evacuated to a pressure of 4 lb per square inch, equivalent to the minimum pressure encountered in flight at 35,000 ft.

Still another feature of the tunnel is its test chamber, which may

Conference on Industrial Hygiene Held in Detroit, March 30, 1945

be *sealed off* from the remainder of the tunnel, thus permitting airplane models in the chamber to be changed or worked on without changing the test pressure.

The Curtiss tunnel, despite its tremendous size and multiplicity of equipment, may be efficiently operated by a crew of three men—a power operator, a balance operator and a tunnel control operator. The entire operation may be performed remotely from the operating *console* located just outside the tunnel.

PAST PRESIDENT'S CERTIFICATE

Kansas City Chapter,
American Society of Heating & Ventilating Engineers

In honor of high achievement, and in acknowledgment of time and effort expended in behalf of our local chapter and our national organization, this certificate is awarded to Everett M. Campbell, who served as Kansas City Chapter President during 1940

Signed this 4th day of January 1945

President D. W. Kelley

Secretary R. F. Jones

At a recent meeting of the Kansas City Chapter of the ASHVE each of the past presidents received a certificate as a testimonial of his service, as shown by E. K. Campbell's Past President's Certificate.

W. N. HADEN, LIFE MEMBER OF ASHVE, HONORED BY *IHVE*

William Nelson Haden of Trowbridge, retired chairman of G. N. Haden & Sons, Ltd., London, was honored recently by the *Institution of Heating and Ventilating Engineers* when he was presented with the Institution's gold medal inscribed "February 8th, 1943. Presented to Mr. William Nelson Haden in recognition of his invaluable services to the Institution for the past 40 years, including 33 years as Honorary Treasurer." Although the award was made in 1943, owing to war conditions the medal could not be obtained until recently, and the presentation took place during an informal luncheon on February 14, 1945, at the Connaught Rooms, W. C. 2, following the annual general meeting of members of the Institution.

Mr. Haden, who is one of the ASHVE's Life Members, became a member of the Institution in 1902, the same year that he joined the Society.

Dr. Oscar Faber, president of the Institution, in making the presentation, mentioned that Mr. Haden served as treasurer for 34 years, and as president of the Institution in 1906 and 1907. He represented the Institution for many years on the International Standardization Committees for copper pipe and pipe threads, malleable fittings, and iron pipe threads.

Mr. Haden was also awarded a bronze medal for a paper on the heating of schools, which he read before an International Conference on School Building. Mr. Haden has always shown great interest in the affairs of the Institution, which owes an enormous debt to Mr. Haden.

In accepting the medal, Mr. Haden stated that he would always look back upon the present occasion as the second proudest day of his life, the proudest day having been when he walked down the church aisle with his wife on his arm. The Institution felt that he was not in any way slighting it by putting the present occasion second to that. Mr. Haden expressed his appreciation and he felt that many changes had taken place since he first joined the Institution 43 years ago, and in looking back it gave him great pleasure to note the development and progress in heating, from the days of slow-combustion stoves and four-inch pipes and the present time.

He expressed his opinion that the work of the Institution would be carried on successfully, and with all the rebuilding and reconstruction that would be taking place after the war, the Institution would continue to occupy a very important place in the public life of the country. He thanked the members very sincerely for the expression of their appreciation of the very little service that he rendered to the Institution, and concluded his remarks by assuring them that he would always follow its work with very great interest.

In March 1929 the Council of the Society elected Mr. Haden to join the small but distinguished group of Life Members. Although retired from active business, he maintains interest in Society affairs and its meetings.

The Spirit of '76 Still Lives

The original photograph of the Marine Flag Raising atop Mount Suribachi on Iwo Jima was taken by Joe Rosenthal of the Associated Press. The composite interpretation of the Spirit of '76 was created by The New York Sun.

7th War Loan
May 14-June 30

A. C. Willard

DR. WILLARD TO RETIRE IN 1946

Dr. A. C. Willard, president of the University of Illinois, will retire July 1, 1946 according to the announcement of the University Board of Trustees and his successor will be Dr. George D. Stoddard, New York State Commissioner of Education and President of the University of the State of New York.

Dr. Willard has served as president of the University of Illinois since 1934, after having headed the engineering school for a number of years. Under his administration Illinois has grown to be one of the largest universities in the country with a student body of 12,000 and a faculty of over 1000.

Dr. Willard served as president of the Society in 1928 and has held membership since 1914. He received the F. Paul Anderson Medal in 1936 for "his outstanding work as an engineer, a teacher and an author in the fields of heating, ventilating and air conditioning; for his outstanding service as a consultant on the ventilation of the Holland Tunnel, the United States Capitol and the proposed Chicago Subway; for his outstanding work in research and for the service he rendered to the Society as a member, as an officer and as technical adviser to its Committee on Research."

DR. ROSE HEADS COMMITTEE ON CHIMNEYS AND FIREPLACES

Dr. H. J. Rose, Director of Research and Vice-President, Bituminous Coal Research, Inc., Pittsburgh, Pa., has been named chairman of the Subcommittee on Chimneys and Fireplaces, of the *American Standards Association*. The committee has been instructed to develop construction codes and specific performance requirements for chimneys, fireplaces, smokepipes, and dampers.

A progress report submitted at a recent meeting of Committee A52 emphasized new chimney problems resulting from recent trends in housing design and new materials of construction. Much additional engineering information is needed to write satisfactory codes. Government research now in progress is supplying some of the information needed.

Dr. Rose, a member of the ASHVE, is now serving as a member of its Committee on Research.

COUNCIL MEETS IN CHICAGO

A regular meeting of the Council was held at the Palmer House, Chicago, Ill., May 14, with the following members present: Dr. C.-E. A. Winslow, President, C. M. Ashley, L. T. Avery, J. F. Collins Jr., W. A. Danielson, E. N. McDonnell, A. J. Offner, H. R. Roth, L. E. Seeley, Ernest Szekely, G. L. Tuve, T. H. Urdahl, and G. D. Winans.

Announcement of the death of the Second Vice President, W. A. Russell, Kansas City, was made and the Council designated A. J. Offner, First Vice President, to draft appropriate resolutions on behalf of the Council, and Messrs. E. K. Campbell, former Treasurer, D. M. Allen, President of Kansas City Chapter, and N. W. Downes, former Council Member, were appointed to officially represent the Officers and Council at Mr. Russell's funeral. In tribute to Mr. Russell's memory it was the Council's decision that the office of Second Vice President would remain vacant for the remainder of this year. A special committee presented a resolution on the death of Comdr. F. C. Houghten, USNR, former Director of the Society's Research Laboratory for over 20 years.

Reports of the Council Committees: Executive, Finance, Membership, Meetings and Standards were received. Among the reports of special committees were Committee on Research, Publication Committee, Committee on Housing Society Office and Laboratory, F. Paul Anderson Award, Committee on Constitution and By-Laws, Chapter Relations Committee and the Admission and Advancement Committee.

One of the major topics of discussion was a plan for research financing and approval was given to a fund raising project which is to be carried out under the direction of a special committee to be designated by the President of the Society.

E. F. HACKETT N. Y. BRANCH MANAGER

Announcement has been made by the Pacific Steel Boiler Division of U. S. Radiator Corp., Detroit, Mich., of the appointment of Edward F. Hackett as Branch Manager of their New York Sales Office located at 101 Park Ave., New York 17, N. Y.

Mr. Hackett was graduated from the Clarkson College of Technology in 1923 with a degree in mechanical engineering. He has been employed by the Corporation since his graduation, and has held responsible positions in the New York, Albany, and Harrison, N. J., offices.

Group of ASHVE Connecticut chapter members at inspection of Nash plant. South Norwalk, April 11, 1945

SUMMARY OF LOCAL CHAPTER MEETINGS

CHAPTER	MEETING DATE	SUBJECT	SPEAKERS	OTHER FEATURES	ATTENDANCE	ATTENDANCE RATIO*
Atlanta	Mar. 19	Weathermaster Conduit System (illustrated with movies and slides)	M. J. Wilson, Engr. Carrier Corp.	M. F. DuChateau reported on Society's Annual Meeting	49	0.85
Central Ohio	Apr. 16	Election of officers — Pres., A. W. Williams; Vice-Pres., T. R. Walker; Secy., H. R. Allonier; Treas., R. B. Breneman	By-Laws and Rules Amended as requested by Constitution Committee	Discussion on Chapter Activities and Operation	23	0.41
Cincinnati	May 8	Election of officers — Pres., E. J. Richard; Vice-Pres., A. W. Edwards; Secy. - Treas., H. K. Jennings	G. V. Sutfin, retiring president, thanked the members for their support during the year	Walter Petry, president of the Cincinnati Technical and Scientific Council, spoke briefly on its features	32	0.64
	Apr. 25	Operation of the Kathabar System	Fred Johnson	G. D. Winans, Detroit, and A. V. Hutchinson, New York, Member of Council and Secretary of ASHVE, were guests	27	0.55
		Development Problems Encountered in Development of Aircraft Heater	Charles Owens			
Delta	May 8	V-E Day Fifteen seconds of silent prayer were offered for V-E Day when Pres. Cressy opened the meeting	Officers elected: Pres., W. H. Grant, Jr.; Vice-Pres., W. P. Oster; Treas., L. K. Nelson; Secy., J. S. Burke; Bd. of Governors: L. V. Cressy, L. V. Busenlener, R. B. Guest	Retiring President Cressy was presented with an engraved fountain pen and pencil set as a token of appreciation of his faithful service to the Chapter	25	0.45
		Heating and Air Conditioning in Latin American Countries	A. J. Offner, 1st Vice-Pres. of ASHVE, New York	A rising vote of thanks was given to Mr. Offner		
Golden Gate	Apr. 4	The Necessity for Building the West	Rex Nicholson, Dir. of Builders of the West, Inc.	Interesting Discussion followed Nominating Committee reported	34	0.42
Indiana	Apr. 27	Central Station Steam Distribution	R. L. Fitzgerald, Vice-Pres., Duluth Steam Corp., Duluth, Minn.	Officers Elected: Pres., G. B. Supple; Vice-Pres., F. G. Tykle; Treas., L. W. Clark; Secy., T. R. Davis; Bd. of Governors: W. C. Bevington, I. W. Cotton, George Jackson	54	0.42
Iowa	Apr. 10	Use of Activated Charcoal in Reclaiming Air in a Conditioning System	Henry Sleik, W. B. Connor Engrg. Co., New York, N. Y.	Pres. W. W. Stuart appointed the Nominating Committee	20	
Kansas City	May 7	Air Conditioning Through Conduits	H. C. Hoffman, Carrier Corp., Chicago, Ill.	L. T. Mart, Chairman, Nominating Committee, announced slate: Pres., R. B. Mason; Vice-Pres., S. L. Furber; Secy., P. C. Leffel; Treas., R. L. Thomas; Board of Governors, D. M. Allen, M. M. Rivard, L. A. Stephenson		

Chapter	Meeting Date	Subject	Speakers	Other Features	Attendance	Attendance Ratio*
Massachusetts	Apr. 17	Electronics Applied to Heating and Ventilating	J. E. Haines, Mgr., Air Cond. Controls Div., Minneapolis-Honeywell Regulator Co.	W. J. Ahearn presided in absence of Pres. D. M. Archer	62	0.55
		Industrial Electronics	Samuel Senior, New England Engr., Industrial Div., Minneapolis-Honeywell Regulator Co.			
Michigan	Apr. 16	The Engineered Btu's Effect on Political Forces	Brig.-Gen. W. A. Danielson, Memphis, Tenn.	A rising vote of thanks was given Gen. Danielson for his instructive and enjoyable talk	56	0.44
		Present Coal Situation (Regulation No. 26)	G. W. Anderson, Serv. Engr., Koppers Coal Div., Detroit	A resolution on death of R. E. Purcell was adopted		
Minnesota	May 7	Study of Weather Tabulation Together with the Building of All Types of Recording Instruments	Paul Cross	Election of Officers: Pres., R. E. Gorgen; Vice-Pres., J. E. Haines; Treas., H. C. Mills; Secy., O. L. Lilja	48	
Montreal	Apr. 16	A Survey of Combustion in Small Underfeed Stokers	Ralph Grossman, Montreal, Que.	A minute of silence was observed in memory of the President of the United States	36	0.50
Nebraska	Apr. 11	The Art of Air Recovery	Henry Sleik, W. B. Connor Engrg. Co., New York, N. Y.	Mr. Sleik illustrated his talk with interesting slides	30	
	Mar. 13	The Story of the Metal Bellows (sound film)		Verne Simmonds reported as Chapter Delegate to Annual Meeting	18	
North Carolina	May 4	The Air Conditioning of the Pentagon Building in Washington, D. C.	C. S. Leopold, Consulting Engr., Philadelphia, Pa.	An interesting discussion period followed	41	0.52
		Presentation to retiring president of ASHVE lapel pin engraved, bearing a diamond as a token of Chapter's appreciation for his services during the past year.		Election of officers: Pres., K. W. Selden, Jr.; Vice-Pres., E. S. Theiss; Secy.-Treas., E. S. DeWitt; Board of Governors, James Marshall, L. L. Vaughan.		
North Texas	Apr. 16	Study of the Proposed Law to License Air-Conditioning Contractors	P. N. Vinther, Consulting Engr.	Discussion followed	34	0.70
Northern Ohio	Apr. 9	Instruments and Methods of Measuring Sound	Prof. Wallace, Case School of Applied Science, Cleveland	G. B. Priester reported on Educational Committee of Cleveland Technical Society Council	71	0.49
		Physiological Aspects of Sound	Allen Wilson, Celotex Corp.			
		The Measurement and Control of Noise	Mr. Sabine, Celotex Corp.			

Chapter	Meeting Date	Subject	Speakers	Other Features	Attendance	Attendance Ratio*
Pacific Northwest	Apr. 20	Joint Meeting with ASRE. Inspection Trip Through the Strato Chamber at Sandpoint Naval Air Station, Seattle	Chief Engineer gave talk explaining operation	Election of officers: Pres., D. C. Griffin; Vice-Pres., R. E. LeRiche; Secy., C. W. Finn; Treas., L. L. Byson	53	0.23
Philadelphia	Apr. 12	Members stood in silent tribute to the President of the United States Package Fuel	J. L. Mooney, Gen. Mgr., White Package Fuel Div., Blaw-Knox	Resolution of sympathy upon passing of K. C. S. Jacobsen and Sidney B. Strouse Election of Officers: Pres., R. D. Touton; 1st Vice-Pres., M. G. Kershaw; 2nd Vice-Pres., E. H. Dafter; Treas., J. O. Kirkbride; Secy., F. H. Buzzard	93	
Rocky Mountain	Apr. 18	Activated Carbon (illustrated with slides)	Henry Sleik, W. B. Connor Engrg. Co., New York, N. Y.	Bill Larimer reported on finances; Ed McEahearn reported for program	30	0.50
St. Louis	Apr. 3	All Year Air Conditioning with Gas	H. C. Pierce, Air Conditioning Div., Servel, Inc.	Report of Nominating Committee was submitted	110	1.64
South Texas	Mar. 16	Advantages of the Gas Turbine	C. A. McKinney, Engr., United Gas Corp., Houston.	Mr. McKinney also spoke on work being done by Central House Heating Committee of A.G.A.	28	
	Feb. 16	Operation and Success of the Commission for Economy	Mr. Crampton of Houston Chamber of Commerce		27	
Southern California	Apr. 11	Are Engineers Allergic to Post War?	Dr. B. M. Woods, Chairman, Finance Committee of ASHVE and Professor of M. E., University of California, Berkeley	Dr. Woods also reviewed the status of Society and its Research Laboratory	61	0.71
Utah	May 2	Electrostatic Precipitron, or Air Cleaner as Applied to Post War Air Conditioning System	S. M. Johns, Branch Mgr., Westinghouse Electric Co.	Mr. Johns' address was enthusiastically received	46	0.83
Western New York	Apr. 9	Steel, Man's Servant	Motion picture depicting various ideas of what the steel companies of the country are doing in the difficulty of war	M. C. Beman reported for Nominating Committee		
Wisconsin	Apr. 16	Experiences as Peace-Time Editor of the Blue Radio Network and as a War-Time Navy Industrial Incentive Officer	Lt. Schuyler Patterson, United States Navy Industrial Incentive Officer.	Films of Navy Combat Action of the Invasion of the Philippines were shown	86	1.33
	Mar. 19	Air Conditioning in the Manufacture of Penicillin	L. T. Avery, Member of Council of ASHVE and Pres. Avery Engrg. Co., Cleveland, Ohio	C. H. Randolph presented the slate of officers for the coming year	46	0.71

*The attendance ratios shown represent the meeting attendance divided by the Chapter membership. These will be useful as a partial indication of interest shown by local chapter members in various types of subjects programmed by other local chapters and may be helpful in deciding on subjects for other chapter meetings.

1886

1945

2ND VICE-PRES. W. A. RUSSELL DIES IN KANSAS CITY

It is with regret that the Council announces the death of William Amberg Russell, Second Vice-President of the Society, on Saturday, May 12, at the Osteopathic Hospital, Kansas City, after an illness of several months.

Born in Chicago in 1886, Mr. Russell was graduated from the University High School, Chicago, and from the University of Michigan, Ann Arbor. Following his graduation he spent two years as superintendent of construction for the central manufacturing district in Chicago. Later he became associated with Spencer Heater Co., Chicago, as boiler salesman. After four years he joined the staff of the Mine & Smelter Supply Co., Denver, Colo., where he furthered the sale of products of the U. S. Radiator Corp. In 1921 he became manager of the Kansas City branch office of the United States Radiator Corp., which position he held when he joined the Society that year.

At the time of his death, Mr. Russell was district manager for the Hoffman Specialty Co. with headquarters in Kansas City. He was a member of the fuel oil panel of the War Price and Rationing Board of Kansas City since its inception three years ago and recently the ration board administrator praised Mr. Russell's activity and interest in the service. He was one of eight members of the panel which pioneered personal service by making trips direct to homes and business offices to solve rationing problems. This panel handled more than 100 million gallons of fuel oil rationing annually and it was declared recently, by an official in Washington, that it was the nation's outstanding panel.

Mr. Russell took an active interest in Society affairs for nearly a quarter of a century, serving as a member of the Council over a period of nine years. He took great pride in interesting new members in Society membership and he served as a member of the Membership Committee for over seven years and an additional two years as Chairman of this committee. As one of the conscientious members of the Kansas City Chapter, he served as its Treasurer in 1921-22; as its Vice-President in both 1923 and 1931; as Secretary in 1930; as its President in 1932, and as a member of its Board of Governors in 1933. In 1934, 1940 and 1941 he was the representative of the Kansas City Chapter on the Nominating Committee of the Society, and in 1935 and 1942 the alternate. At the time of his death he was serving the Society as its Second Vice-President.

Mr. Russell's father, the late M. J. Russell, was collector of the Port of Chicago, editor and owner of the Chicago Chronicle, and had served as president of the park board there. His father was one of President Cleveland's aides.

Mr. Russell was a member of the Delta Kappa Epsilon fraternity from the University of Michigan.

He leaves his widow, Mrs. Belle Hart Lincoln Russell; one daughter, Mrs. Charlotte Russell Caldwell; and one grandson, Robert B. Caldwell III, of Kansas City; four sisters, Mrs. James Weaddock, Saginaw, Mich.; the Misses Ruth, Celia and Jane Russell, all of Chicago; and one brother, L. E. Russell, Chicago.

The Officers and Council of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS extend their deepest sympathy to Mrs. Russell and to the other members of the family.

Funeral services were held on Tuesday, May 15, at the Stine and McClure Chapel, Kansas City, and burial was in Lapeer, Mich. The majority of the Kansas City Chapter members attended the funeral and the Officers and Council were officially represented by Messrs. E. K. Campbell, N. W. Downes and D. M. Allen.

DEATH OF CHARLES G. HEYDON

Charles G. Heydon, a member of the ASHVE since 1922, and a well known sales engineer for Wright-Austin Co., Detroit, Mich., died suddenly of a heart attack in their New York office on May 9, 1945. Mr. Heydon was on a business trip in New York with C. Burt Walter, president of the company, who was with him at the time of his death.

Mr. Heydon was born July 18, 1879 in Kansas City, Mo., and attended the Ward School in that city. His first experience was with the A. A. Nichol, Kansas City, and

after six years he was employed with Hanly and Casey Co., Chicago. After some years with the U. S. Government he entered the contracting business for himself.

Mr. Heydon was associated with Wright-Austin Co. for over 25 years, and was a life member of Ararat Shrine in Kansas City, Mo.

He was highly esteemed by a host of friends, not only in the Society, but in the heating, ventilating and air conditioning field, and was always a prominent figure at the *National Association of Power Engineers'* meetings.

He is survived by his widow, Mrs. Alice Heydon of 2681 Nebraska, Detroit, Mich., and a son, Thomas G. Heydon, who is with the Packard Motor Car Co., Detroit, to whom the Officers and Council of the Society extend their sincerest sympathy.

Candidates for Membership

The Constitution of the Society, as now amended, requires the following mode of procedure in voting on applicants for membership in the Society. All applications for membership are to be sent to the Secretary and the names of applicants and their references shall be printed in the next issue of the Journal of the Society or sent to the members in other approved manner as ordered by the Council. When replies are received from references, the Candidate's application shall be submitted to and acted upon by the Committee on Admission and Advancement as soon as possible.

When the Committee on Admission and Advancement has acted favorably upon a Candidate's application and assigned his grade, the Council shall vote upon the election of the proposed Candidate for membership by letter ballot. During the past month 60 applications for membership have been received and the names of these men and their sponsors are published in the following list.

Members are requested to scrutinize the list with care. The Committee on Admission and Advancement, and in turn, the Council, urge members to assume their share of responsibility of receiving these candidates into membership by advising the Secretary promptly of any whose eligibility for membership is in any way questioned.

All correspondence in regard to such matters is strictly confidential, and is solely for the good of the Society, which it is the duty of every member to promote.

Unless objection is made by some member by June 15, 1945, these candidates will be ballotted upon by the Council. Those elected to membership will be notified by the Secretary immediately after election.

CANDIDATES	REFERENCES	
	Proposers	*Seconders*
AIKIN, FRANK W., Pres., Northern Controlled Heat Co., Inc., Watertown, N. Y.	J. W. Stevens D. D. Wile	W. L. Lynch Gordon Wheler
BARRY, WILFRED W., Supvsr., Barry Sheet Metal Co., Ltd., Edmonton, Alta., Canada.	O. J. Hatch F. L. Chester	Elnar Anderson F. T. Ball
BASSEVITCH, ABRAHAM, Bethlehem Steel Corp., Staten Island, N. Y.	*R. L. Katzenstein *W. C. Battenberg	*Irving Walter *Kenneth Baetz
BEAUCHAMP, JOHN H., Owner, Heating & Refrigeration Maintenance Co., Houston, Texas.	C. L. Boehler J. C. Lewis	D. S. Cooper B. P. Fisher
BERGAN, JOHN R., Mgr., Minneapolis-Honeywell Regulator Co., Modu-flow Div., New York, N. Y. *(Advancement)*	C. S. Koehler L. B. Belford	Ernest Graber J. H. Broome
BISHOP, FREDERICK W., Crane, Ltd., St. Johns, Newfoundland.	*C. H. Conroy *W. L. Halfyard	*J. E. Hoskins *W. D. McCarter
BOOTH, ROGER W., Chief Engr., The Lennox Furnace Co., Marshalltown, Ia.	R. S. Stover E. O. Olson	C. H. McGuiness R. K. Smith
BROKAW, GEORGE K., Htg. & Vent. Engr., San Francisco, Calif. *(Advancement)*	C. E. Bentley G. M. Simonson	James Gayner C. L. Peterson
BOWEN, JUDSON P., Branch Mgr., Penn Electric Switch Co., Atlanta, Ga.	W. J. McKinney M. F. DuChateau	M. W. Wise R. F. Hahn
BURKLE, JAMES L., V-12 Engrg. Student, Yale University, New Haven, Conn.	L. E. Seeley *L. C. Lichty	*F. W. Keaton *C. W. Phelps
COCKMAN, THOMAS E., B. F. Sturtevant Co. of Canada, Montreal, Que., Canada.	A. M. Madden G. L. Ballantyne	F. A. Hamlet Leo Garneau
COFFEY, GEORGE B., Service Engr., A. M. Byers Co., Chicago, Ill.	C. M. Burnam, Jr. A. O. May	C. E. Price J. J. Hayes
COLLIER, J. ROBERT, Dist. Repr., Taco Heaters, Inc., Minneapolis, Minn.	F. H. Schernbeck E. T. Houlihan	H. M. Hart G. W. Bornquist
COLLINS, GEORGE J., Supt., Barber Plumbing Co., Houston, Tex.	A. F. Barnes D. M. Mills	W. J. Way R. F. Taylor
CONNELL, MAURICE H., Sr. Partner, Maurice H. Connell & Assoc., Miami, Fla.	C. L. Templin C. V. Fenn	Leo Sudderth, Jr. R. S. Arnold
COOK, WILLIAM L., Htg. & Plbg. Contr., Cheyenne, Wyo.	H. J. Woehlke A. W. Cooper	E. J. McEahern J. T. Sheehan
COONEY, JAMES L., Mgr., Cooney Co., Syracuse, N. Y.	R. E. Cherne N. E. Sheldon	B. R. McCumber G. F. Keane
CORRIGAN, THOMAS J., Vice-Pres., Corrigan Co., St. Louis, Mo.	George Myers W. J. Oonk	C. R. Davis H. C. Sharp
COSTA, CIRO A., Merchandise Engr., Westinghouse Electric International Co., Buenos Aires, Argentina, S. A.	L. G. Huggins W. A. Minkler	I. R. Cummings J. J. Tillotson
COWAN, ARMAND, Pres., Stuart Cooling Corp., New York, N. Y.	Jack Kreiner W. E. Heibel	Ernest Graber P. J. Barbieri
DEMPSEY, EDWARD P., Htg. & Vent. Engr., Glenn L. Martin-Nebraska Co., Omaha, Nebr.	A. L. Ottum G. E. Merwin	W. R. White D. D. Williams
FULLER, CLAYTON W., Engr., Dixie Manufacturing Co., Inc., Baltimore, Md.	J. W. Toohey E. H. Taze	H. L. Dodson R. L. Leilich
GERDSEN, ARNO H., Pres., The A. H. Gerdsen Co., Cincinnati, Ohio.	A. W. Edwards H. K. Jennings	W. A. Juergens E. W. McNamee

GILBOY, WILLIAM O., Engr., Cooney Co., Syracuse, N. Y.

GILLESPIE, HARVEY M., Patent Atty., 105 W. Adams St., Chicago, Ill.

HABASHI, FAWZI, Student, Fouad First University, Cairo, Egypt.

HANNAN, LLOYD F., Owner, Ace Sheet Metal Works, San Francisco, Calif.

HEISINGER, FREDERICK W., Mgr., Heating Div., Benedict & Benedict, Pasadena, Calif.

HELWIG, E. CORNELIUS, Asst. to Pres., Tanner & Co., Indianapolis, Ind.

HESS, ARMIN E., Branch Mgr., General Controls Co., Houston, Tex.

HICKMAN, HERBERT V., Gen. Mgr., Neil H. Peterson Co., San Francisco, Calif. *(Advancement)*

HUPP, HARLEY L., Dist. Commercial Sales Mgr., York Corp., Cleveland, Ohio.

ILOVITCH, ELI L., Student Engr., Air-Conditioning Engineering Co., Montreal, Que., Canada.

ISLEY, GARNET H., Assoc. Engr., United States Engineer Office, Seattle, Wash.

KELLY, HERBERT C., Pres., The George Howard Co., New Haven, Conn.

LINDSTROM, ALVIN L., Professional Engr., Atlanta, Ga.

LIVAUDAIS, MARCEL, Chief Draftsman and Mech. Engr., 8th Naval District, New Orleans, La.

LOCHER, DAVID E., Pres., Coolidge Locher Co., Corpus Christi, Tex.

LOFTUS, ROBERT G., Maintenance Engr., Canada Cycle & Motor Co., Weston, Ont., Canada.

MACDONALD, GEORGE D., Engr., The Holyoke Valve & Hydrant Co., Holyoke, Mass.

MARTIN, HENRY L., Div. Hd., Boston Edison Co., Boston, Mass.

MINAKER, MELVIN E., Sales Engr., Minneapolis-Honeywell Regulator Co., Ltd., Calgary, Alta., Canada.

MOSHER, HAROLD A., Mech. Engr., Eastman Kodak Co, Rochester, N. Y.

OLDS, STEPHEN T., Sales Mgr. & Engr., William C. Maunz Co., Buffalo, N. Y.

OWEN, CHARLES E., JR., Petty Officer, Metalsmith 2/c, USNR, c/o Fleet P. O., San Francisco, Calif.

OWEN, FRANK W., Petty Officer, Ship Fitter 1/c, USNR, Camp Endicott, Davisville, R. I.

PATTERSON, HOWARD V., Owner, American Engineering Co., Kansas City, Mo.

QUIST, OSWALD F., JR., Installation & Service Mgr., Minneapolis-Honeywell Regulator Co., New York, N. Y.

RAINEY, HUGH D., Pres., Rainey Roofing & Sheet Metal Co., Joplin, Mo.

RASTRICK, R. J., Supt. Engr., Vale & Co., Ltd., Christchurch, New Zealand.

RIND, KAREL, Engr., Vale & Co., Ltd., Christchurch, New Zealand.

SPITZ, NATHANIEL, Jr. Partner, City Coal Co., New London, Conn.

SWATS, WILLIAM F., Asst. Supt. of Bldgs., Vanderbilt University, Nashville, Tenn.

TIMMERMAN, WALTER C., Engr., Air Cond. Dept., Straus-Frank Co., Houston, Texas.

WARD, LAWRENCE C., Dist. Repr., The Herman Nelson Corp., Syracuse, N. Y.

WEINER, HYMAN R., Student, Case School of Applied Science, Cleveland, Ohio.

WENINGER, MERLE, Dist. Mgr., The Powers Regulator Co., Syracuse, N. Y.

WHEELER, B. J., Lt., U. S. Maritime Service, Vancouver, Wash.

WHITTEMORE, WILLIAM M., JR., Jr. Cadet Engr., Carbide & Carbon Chemical Corp., Nashville, Tenn.*

WIGLE, KENNETH G., Pres., Bruce Wigle Plumbing & Heating Co., Detroit, Mich.

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*Non-member.

R. E. Cherne	B. R. McCumber
N. E. Sheldon	G. F. Keane
O. J. Prentice	E. B. Ericsson
A. O. May	J. S. Kearney
H. M. Zaki	
James Gayner	R. B. Holland
C. L. Peterson	H. V. Hickman
Leo Hungerford	R. A. Lowe
Art. Theobald	Maron Kennedy
J. A. Nyland	S. E. Fenstermaker
G. B. Supple	G. O. Jackson
B. P. Fisher	D. S. Cooper
F. C. Brandt	C. L. Boehler
N. H. Peterson	C. L. Peterson
K. O. Alexander	R. C. Cushing
W. E. Keist	T. F. Campbell
E. E. Smyers	G. O. Weddell
S. S. Colle	F. J. Friedman
A. B. Madden	*J. D. Fry
C. D. Berkeley	E. J. Rosen
O. W. Priebe	Roy Conrad
T. J. Converse	G. F. Nieske
L. O. R. Clark	C. J. Lyons
W. J. McKinney	L. F. Lawrence, Jr.
M. F. DuChateau	I. B. Kagey
W. H. Dudley, Jr.	G. E. May
N. J. Helwick	J. S. Burke
R. C. Holsworth	J. A. Walsh
I. I. Bock	W. A. Ebert
H. R. Roth	W. H. Evans
*T. C. Agnew	V. J. Jenkinson
C. R. Swaney	W. T. Jones
T. H. Brigham	C. W. Larson
J. F. Tuttle	E. G. Carrier
J. F. Collins, Jr.	J. W. Brinton
W. H. Evans	H. G. S. Murray
V. J. Jenkinson	J. P. Fitzsimons
Henry Peck	J. Q. Treadway
R. P. Cook	R. E. Cherne
F. J. Weber	F. A. Moesel
Herman Seelbach, Jr.	J. S. Meyer
C. E. Owen	Louis Steckhan
W. J. MaGirl	C. W. Youngblood
C. E. Owen	Louis Steckhan
W. J. MaGirl	C. W. Youngblood
D. M. Allen	M. A. Disney
P. C. Leffel	L. A. Stephenson
C. S. Koehler	Ernst Graber
J. H. Broome	L. B. Belford
D. M. Allen	E. K. Campbell
P. C. Leffel	W. E. Howarth
H. A. L. Vale	G. W. Davies
H. A. L. Vale	G. W. Davies
J. J. Mirabile	*John Baratz
*M. A. Doering	*Wilbur Baratz
C. S. Leopold	Foskett Brown
*F. J. Lewis	W. C. Armistead
F. C. Brandt	J. A. Walsh
C. L. Boehler	R. L. Prussing
H. F. Yeazel	P. D. Robson
J. W. Stevens	C. F. Woese
G. B. Priester	*W. A. Lynam
L. G. Seigel	*D. K. Wright, Jr.
C. F. Woese	P. D. Robson
H. K. Ormsby, Jr.	J. H. Carpenter
B. W. Farnes	W. J. Widmer
E. E. Carroll	J. R. Lynch
*D. H. Ladd	*G. W. Sutton
*E. T. Ebert	*W. D. Harmon
C. A. Strand	A. E. Knibb
M. B. Shea	W. H. Old

Candidates Elected

In the past issues of the Journal of the Society the names of the following men were listed as Candidates for Membership. The membership grade of each Candidate has been assigned by the Committee on Admission and Advancement and balloted upon by the Council. We are now instructed by the Council to post herewith, as required by Art. B-III, Sec. 8, of the By-Laws, the following list of candidates elected:

MEMBERS

AITKEN, MILTON L., Gen. Mgr., Propellair, Inc., Springfield, Ohio.

ALEXANDER, JOHN W., Mech. Engr., Public Buildings Administration, Washington, D. C.

BEAIRD, BENJAMIN J., Chief Engr., Charles G. Heyne & Co., Houston, Tex. *(Reinstatement)*

CAMPBELL, GUY C., Sr. Partner, Campbell-Elsey Co., Salt Lake City, Utah.

CHAR, RAGHAV D., Owner, Industrial & Agricultural Engineering Co., Bombay, India.

DAVIS, JOHN C., Pres. & Mgr., J. C. Davis, Ltd., Winnipeg, Man., Canada.

DEAN, VERNON C., Cons. Engr., Grand Rapids, Mich.
DUTTON, GAYLE R., Partner, Western Fiberglas Supply, Ltd., San Francisco, Calif.

FAVA, ALBERT A., Plant Engr., Atlantic Gelatin Co., Inc., Woburn, Mass.
FENN, CHARLES V., Dist. Mgr., Carrier Corp., Atlanta, Ga. *(Reinstatement and Advancement)*

HELMS, LOYD J., Mech. Engr., English & Lauer, Inc., Los Angeles, Calif.
HOFFMAN, CHARLES F., Mech. Engr., Bellman, Gillett & Richards, Toledo, Ohio. *(Reinstatement and Advancement)*

JANES, THOMAS J., Mech. & Elec. Engr., University of California, Berkeley, Calif.

JUNGELS, ALTON J., Constr. Engr., R.C.A., Camden, N. J.

KERR, GERALD C., Acoustical Engr., Taylor Seidenbach, Inc., New Orleans, La. *(Advancement)*

LA ROW, LEO E., Indus. Gas Engr., Central New York Power Corp., Utica, N. Y.

MCQUITTY, ROY M., Steam Util. Engr., Union Electric Co. of Missouri, St. Louis, Mo.
MANIER, RALPH L., Indus. Htg. & Air Cond. Engr., Central New York Power Corp., Syracuse, N. Y.
MENCH, JOHN G., Mech. Engr., James Stewart Corp., Chicago, Ill.
MEYER, JOHN S., Sales Promotion Mgr., W. A. Case & Son Manufacturing Co., Buffalo, N. Y. (*Reinstatement*)

NELSON, WALTER L., Chief Mech. Engr., District Government, Washington, D. C. *(Advancement)*

PHILIPS, EDWARD W., Dist. Mgr., Walworth Co., Cleveland, Ohio.
PIERCE, HAROLD C., Asst. Mgr., Air Conditioning Div., Servel, Inc., Evansville, Ind.

RADOTINSKY, JOSEPH W., Archt. Engr., Kansas City, Kans.
RIESMEYER, EDWARD H., Jr., Htg. Engr., Schaffer Heating Co., Pittsburgh, Pa. *(Advancement)*
ROBINSON, FREDERIC W., Dir. of Research, Hanovia Chemical & Manufacturing Co., Newark, N. J.

SCHREIBER, W. F., Owner, Schreiber Institute of Refrigeration, Kansas City, Mo.
SEITZ, RALPH C., Central New York Power Corp., Syracuse, N. Y.
SHARPE, VERNON W., Vice-Pres., Dynamic Air Engineering, Inc., Los Angeles, Calif.
STANGER, WILLIAM F., Sales Engr., Robinson & Stanger, Pittsburgh, Pa.

THOMAS, BENJAMIN F., Jr., Mech.-Elec. Engr., Moran, Proctor, Freeman & Mueser, New York, N. Y.

VAN WAGENEN, EDWARD, Mech. Engr., U. S. Naval Air Station, Jacksonville, Fla.

WHELAN, LEO, Chief Engr., Ray Oil Burner Sales, Inc., New York, N. Y. *(Advancement)*
WILSON, HARRY F., Cons. Engr., St. Louis, Mo.

ASSOCIATE MEMBERS

ALLEN, ABRAHAM B., Office Mgr., Oil Burning Engineers, Inc., Chicago, Ill.
ALLEN, GEORGE W., Maintenance Mechanic, U. S. Coast Guard, Brooklyn, N. Y.
BALDWIN, CHARLES W., Vent. Engr., U. S. Rubber Co., North Wilbraham, Mass.
BEALS, A. P., Gen. Mgr., Western Service Co., Fargo, N. D.
BICKELL, GEORGE C., Sales Engr., Tutein Equipment Co., Pittsburgh, Pa.
BOSTROM, H. R., Owner, Bostrom Sheetmetal Works, St. Paul, Minn.

CANTERBURY, HOWARD M., Repr., J. A. Walsh & Co., Inc., Houston, Tex.
CANTWELL, ALGERNON B., Solid Fuel Engr., Kansas City Coal Service Institute, Kansas City, Mo.
CARNS, VERNON J., Application Engr., Minneapolis-Honeywell Regulator Co., Detroit, Mich.
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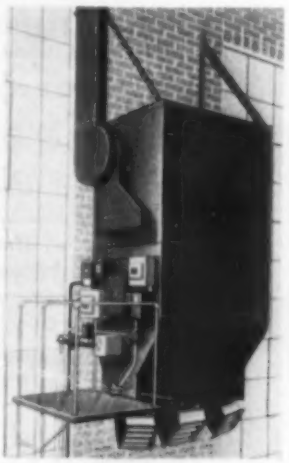

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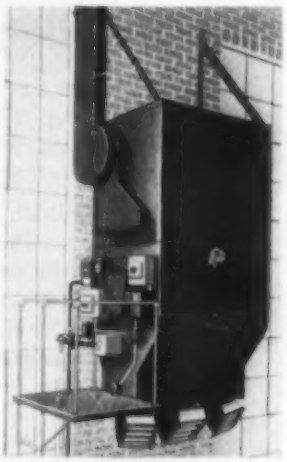

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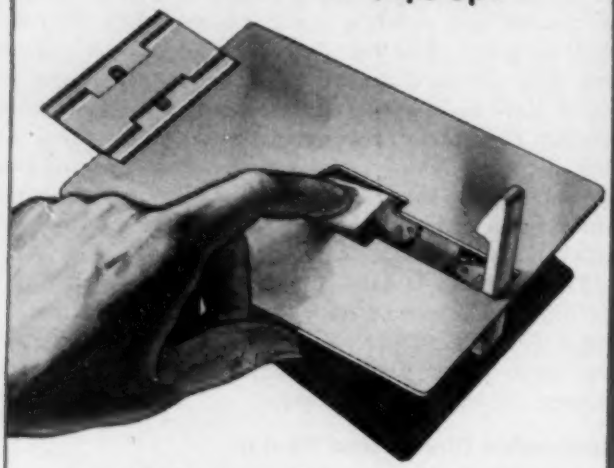
MUTILATED

Press and the door pops open!



Save Time—Save on Cost

with this quick-opening FLUSH door latch

Hartwell's new *flush* door latch speeds the opening and closing of inspection and access doors. On many installations it can be substituted for more expensive hardware.

The Hartwell latch can be used on metal, plastic or wood, and on doors of varying sizes and thicknesses. It can be used on inspection and access doors, cover plates, cabinet and locker doors, and flush fixtures. By eliminating projecting knobs, it improves streamlining.

PRESS to open!
Pressure on the trigger releases the bolt, and the door pops open.

PRESS to lock shut!
Pressure on the bolt, when the door is closed, locks it shut.

MADE OF STAINLESS STEEL, the Hartwell latch is sturdy and corrosion resistant. Twin springs, control-

MUTILATED

Water Heater

No. 2820—The new "Adsco Type R" instantaneous water heater is compact in size with a steel shell and a 1¼ in. OD No. 16 BWG copper U-tube removable heating element. It is of the low friction loss type for use with a gravity recirculation system, or where minimum friction loss in the water space is desirable, says

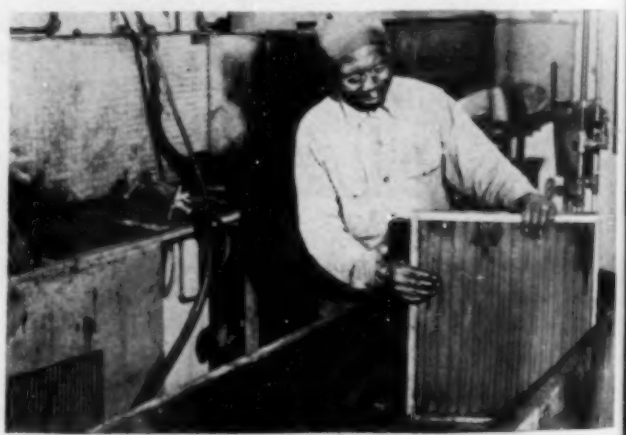
the manufacturer, the American District Steam Co., 25 Bryant St., North Tonawanda, N. Y. The steam flows through the tubes and the water in the shell.

Available in 22 sizes, it has numerous applications in commercial and industrial buildings such as providing hot water for domestic use in apartments, hotels, schools, institutions, and industrial plants, or hot water for process equipment in cooking, sterilizing or cleaning operations. It may be used also as a converter to heat water in a conventional hot water heating system or in connection with radiant heating installations.

Air Filter Cleaner

No. 2821—A new process for the chemical cleaning of air filters, including air conditioning, engine, marine, and aircraft, has been developed by Turco Products, Inc., of 6135 S. Central Ave., Los Angeles 1, Calif.

This process, says the manufacturer, eliminates the necessity of using distillate and other materials and



shortens the time required for the complete operation. The filter is removed and immersed for 6 min in a tank of cold "Aktiv." The filter is then removed from the tank and given a cold water hosing to flush away dirt and grease, dried in a stream of compressed air, and dipped into the manufacturer's specified oil.

The manufacturer claims that there is no attack on galvanized iron and that the clean filter is left odorless.

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To conduct and cool the water supply of his Grecian home town, he bored a 4200-foot pipe channel through a mountain!

Modern heat transfer engineers know something far better than bare pipe for cooling: ***FIN*** coils transfer heat much more efficiently.

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Greater efficiency • Smaller size
• Lighter weight • Lower cost

May we send you our Blast Coil Bulletin?

Marlo Heat Transfer Surface

Ball-Bonded Blast Coils—Cooling and Heating • Air Conditioning and Refrigeration Apparatus • Industrial Blower Units • Unit Coolers. • Evaporative Condensers and Coolers • Low Temperature Apparatus.

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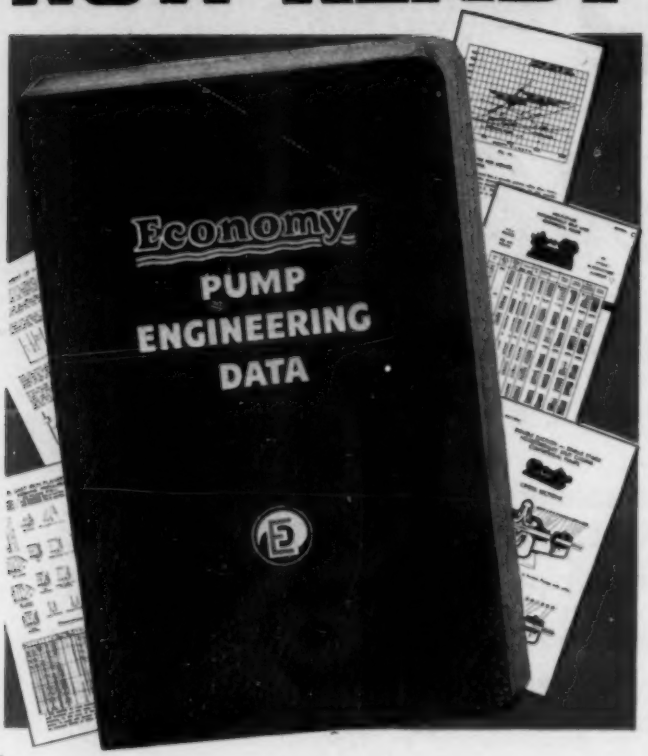

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Air Distribution Panels

No. 4972—A preliminary engineering manual of some 40 pages, in mimeographed form, has been issued by the Multi-Vent Div. of the Pyle-National Co., 1334 N. Kostner Ave., Chicago 51, Ill., on its panels for "uniform, no draft air distribution," which are available in types for the architectural or construction field and for railroad cars. Features of the units are described in detail, information on where to specify them is included, and numerous notes and drawings on system and duct design are presented. There is also data on balancing the system, list prices and weights, etc.

Automatic Arc Welding Process

No. 4973—The "Lincolnweld" process of automatic shielded arc welding is described in a 28 page bulletin issued by the Lincoln Electric Co., 12818 Coit Rd., Cleveland 1, Ohio. In this process, the weight of flux consumed as slag covering is about equal to the weight of electrode metal, which—says the manufacturer—allows the use of higher current with the assurance of complete protection of the deposited metal for higher speeds and lower costs. Granular flux is deposited on the joint to be welded, deep enough to cover the completed weld, and bare electrode is power-fed into the blanket of flux. Installations illustrated include the welding of boiler drums on ASME and API work, chemical pressure vessels, tanks for air compressors, heat transfer tubes, and other items.

Blind Rivets

No. 4974—A 16 page illustrated manual (451) on blind rivets has been issued by the Huck Mfg. Co., 2480 Bellevue Ave., Detroit 7, Mich. It explains the principles of the blind rivet, and gives instructions on selecting the proper length rivet, drilling or dimpling the material, driving the rivet, and other data.

Branch Pipe Outlets

No. 4975—A 32 page manual, pocket size, has been published by the Bonney Forge & Tool Wks., Tilghman St. and Meadow St., Allentown, Pa. Compiled for men responsible for piping, this handbook explains and illustrates the four steps in installing "full pipe strength outlets" by the "WeldOlet" method, and also describes the tools and fittings used. Fittings are available for butt welded, threaded, and socket welded branch pipes.

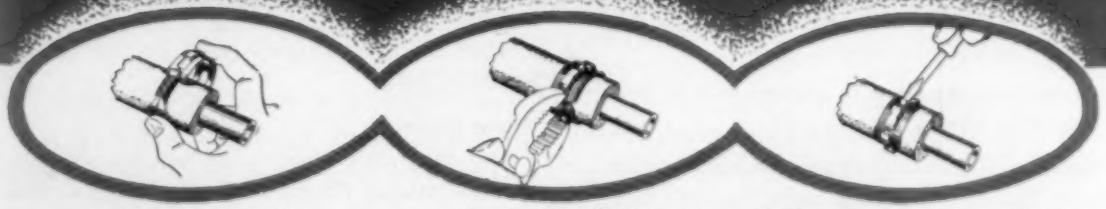
Controls Service Manual

No. 4976—General Controls Co., 801 Allen Ave., Glendale 1, Calif., has published a 30 page service and instruction manual (S1-100) on gas valves, pilot gen-

Man-What a Hose Clamp!

New Speed Clamp* Features

1. Exclusive, self-locking ratchet type design.
2. Lightest weight—lowest profile—sturdy spring steel construction.
3. Uniform circumferential pressure—no pinch or bind.
4. Faster and easier to install or remove.



Latch by hand | Lock with pliers | Remove with screw driver

Widely used throughout military aircraft. May be used over and over again. Sizes from ½" O.D. up. In writing for samples, please give outside diameter of hose with fitting inserted.

TINNERMAN PRODUCTS, INC.
2018 FULTON ROAD CLEVELAND 13, OHIO

In Canada: Wallace Barnes Co., Ltd., Hamilton, Ont. In England: Simmonds Aerocessories, Ltd., London

Speed Clamps for hose connections are engineered and produced by the manufacturers of the famous SPEED NUT shown above.

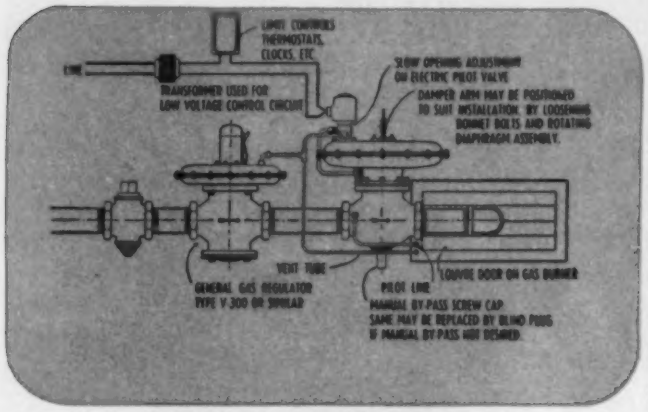
*Trade Mark

Speed Nuts PATENTED Trade Mark Reg. U. S. Pat. Off.

FASTEST THING IN FASTENINGS

Insist on these 5 FEATURES

For efficiency, safety and economy, specify the ONE valve that answers *all* your requirements for industrial and commercial burners and furnaces.


LIMIT CONTROLS THERMOSTATS, CLOCKS, ETC.
TRANSFORMER USED FOR LOW VOLTAGE CONTROL CIRCUIT
SLOW OPENING ADJUSTMENT ON ELECTRIC PILOT VALVE
DAMPER ARM MAY BE POSITIONED TO SUIT INSTALLATION BY LOOSENING BONNET BOLTS AND ROTATING DIAPHRAGM ASSEMBLY.
VENT TUBE
LOUVRE DOOR ON GAS BURNER
GENERAL GAS REGULATOR TYPE V-300 OR SIMILAR
PILOT LINE
MANUAL BY-PASS SCREW CAP SAME MAY BE REPLACED BY BLIND PLUG IF MANUAL BY-PASS NOT DESIRED

GENERAL CONTROLS
Type B-55
Slow Opening Gas Valve

Here, in one sturdily-constructed easily-installed valve, you get everyone of these necessary features.

1. Adjustable opening time—5 to 60 seconds.
2. Widest operating pressure range—handles up to 5 lbs.
3. Widest range of sizes—available from ¾" to 6" i.p.s. for manufactured, natural or L. P gases.
4. Ample power for louvre control. Damper arm easily rotated to any desired position.
5. Low current consumption. In sizes up to 1½" i.p.s. 8 watts; 2" to 6"—14 watts.

The advanced design of this valve has made it the choice of industry. Simplicity of design makes this unit foolproof and trouble-free. Fast closing time is fixed, regardless of opening adjustment. The 3-way pilot valve is operated by the quiet General A.C. Solenoid. B-55's are fail-safe in the event of diaphragm rupture, current failure or binding damper mechanism.

Request new Service and Instruction Manual on Automatic Gas Heating Controls, No. SI-100.

GENERAL CONTROLS
801 ALLEN AVENUE GLENDALE 1, CALIF.

FACTORY BRANCHES: PHILADELPHIA · ATLANTA · BOSTON · CHICAGO
KANSAS CITY · NEW YORK · DALLAS · DENVER · DETROIT · CLEVELAND
HOUSTON · SAN FRANCISCO · SEATTLE · PITTSBURGH
DISTRIBUTORS IN PRINCIPAL CITIES

erators, thermostats, diaphragm valves, low pressure gas regulators, and other gas heating controls. Service troubles, causes, and remedies are listed.

Corrosion in Unit Heaters

No. 4977—D. J. Murray Mfg. Co., 1002-24 Third St., Wausau, Wis., describes corrosion and its influence on unit heaters in a 12 page booklet which contains technical information on preventing corrosion, what metals are vulnerable to corrosion, and the selection of units.

Duplicating Machines

No. 4978—A new 40 page catalog (45-8) has been issued by the O'Neil-Irwin Mfg. Co., 316 Eighth Ave., S., Minneapolis 15, Minn., covering the company's "Di-Acro System of Die-less Duplicating." Pictures and text describe industrial uses of these machines, including benders, brakes, and shears.

Fans

No. 4979—A 58 page bulletin (101) on "Massachusetts Design 4 Power Fixed" fans for air conditioning, heating, ventilating, and general industrial applications has been published by the Bishop & Babcock Mfg. Co., 4901 Hamilton Ave., Cleveland 14, Ohio. These fans are available in two classes, I for total pressure 3¾ in. WG and maximum tip speed of 9000 fpm, and II for total pressure 6¾ in. WG and maximum tip speed of 12,000 fpm. Construction features are described and illustrated carefully, extensive rating tables are given, and dimension tables and drawings for numerous arrangements are shown. There is also a large friction and duct sizing chart for both round and rectangular ducts.

Fans and Blowers

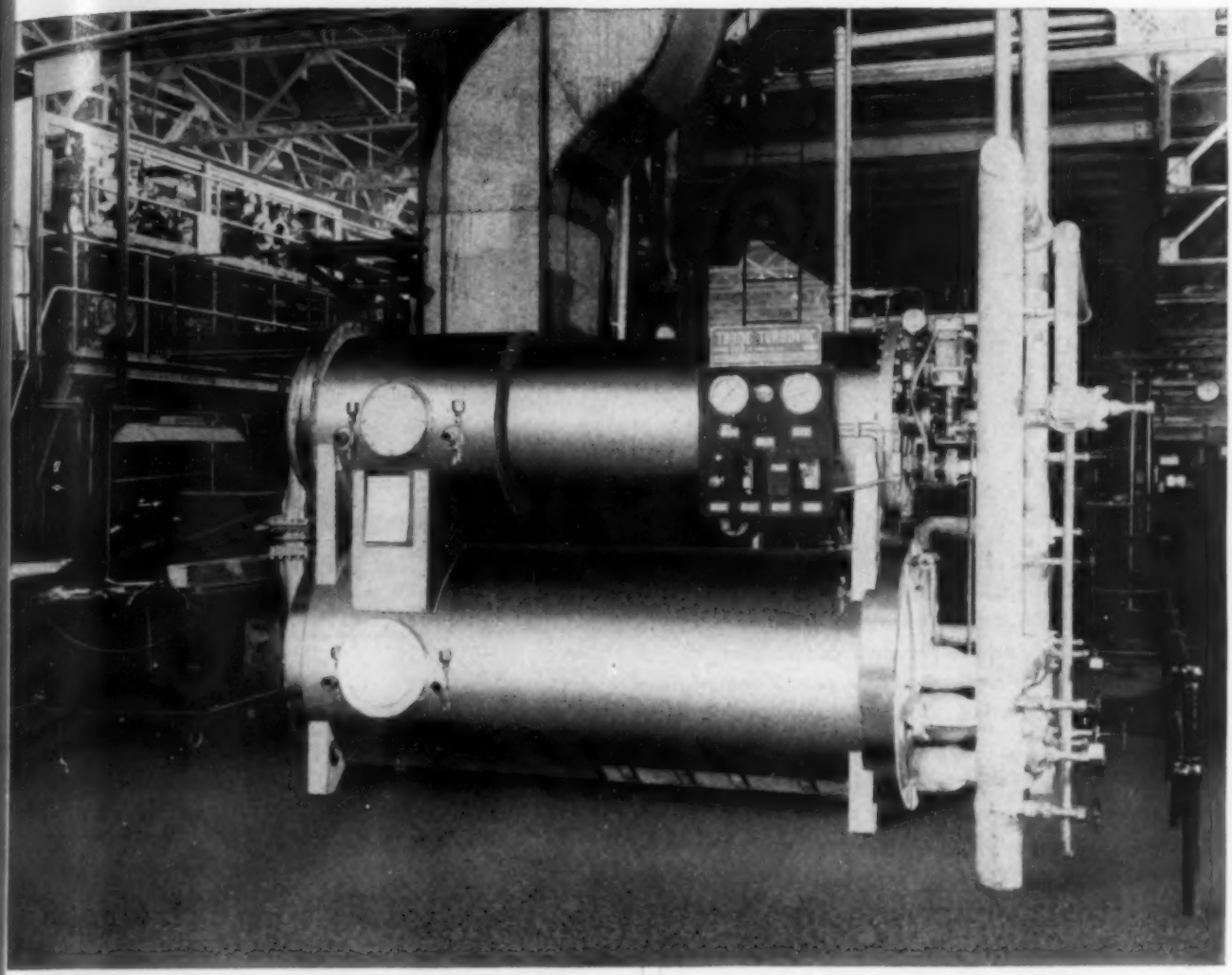
No. 4980—A 12 page illustrated bulletin (1601) has been published by the Hartzell Propeller Fan Co., P.O. Box 909, Roosevelt Ave., Piqua, Ohio, on its tubeaxial and vaneaxial fans and blowers. The new vaneaxial blower, says the manufacturer, will move air efficiently against 8 in. water gage, and by belt drive speed-up, against 16 in.

Fiber Glass

No. 4981—An eight page bulletin published by the Owens-Corning Fiberglas Corp., Nicholas Bldg., Toledo 1, Ohio, gives facts about "Fiberglas" for design engineers. It tabulates the various products made of this material, showing the forms and sizes, the major properties, and the principal uses of each. This material can perform a service, says its manufacturer, "wherever heat is conserved, controlled, or excluded; wherever sound transmission must be reduced, wherever air is cleaned or conditioned," and in many other applications.

Flow Control Valves

No. 4982—Automatic Switch Co., 41 E. 11th St., New York 3, N. Y., has issued a 12 page circular (200) describing its line of valves for the automatic and remote control of the flow of liquids and gases. Included in the circular are pictures and descriptions of safety shutoff and trip valves, pilot valves, explosion-proof valves, filters, strainers, and special valves.



HOW TRANE EQUIPMENT IS COOLING *HOT PAPER*

At the W. F. Hall Printing Company, Chicago, mammoth rotary presses print four superimposed colors on both sides of a web of paper traveling at high speed.

To eliminate smearing or smudging at maximum operating speeds it was necessary to install a gas drying oven which operated at 1500°. However, this raised the temperature of the paper to a point where it was no longer possible to maintain a high standard of accurate color register.

The problem was solved by installing two 70-ton Trane Turbo-vacuum compressors to cool the paper to normal room temperature . . . accomplished by supplying chilled water from the versatile Trane Turbo-vacuum compressors to rolls, around which the heated paper passed after the drying operation. These water cooled rolls restored the paper to the normal temperature necessary for the extremely accurate color register.

This is just another case where Trane, manufacturing engineers of cooling, heating and air handling equipment, has been called upon to solve an unusual problem in industry.

For the architects, engineers, contractors, builders of America who are planning today for tomorrow's building and processing, Trane has the products, the knowledge, and the production facilities. When you have a cooling problem, whether for comfort or process, call on Trane first.

TRANE

THE TRANE COMPANY LA CROSSE, WISCONSIN

TRANE COMPANY OF CANADA, LTD., TORONTO

AIR CONDITIONING · · HEAT TRANSFER · · AIR HANDLING EQUIPMENT

SOLVE YOUR VIBRATION PROBLEMS IN ADVANCE

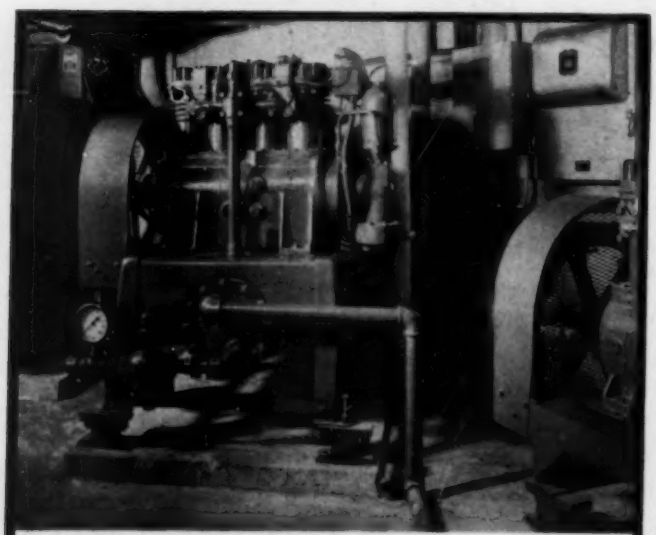
with . . . KORFUND VIBRATION CONTROL

Uncontrolled vibration from fans, motors and compressors can easily offset the benefits expected of an air conditioning installation. That is why so many architects, engineers and contractors "figure in" Korfund Vibration Control as a part of the original equipment. They solve their vibration problems in advance.

For many years Korfund engineers have made a special study of vibration in air conditioning. The result is an accumulation of experience which is invaluable in the selection of the ideal isolating material and isolator design for each individual unit of a system.

Why not let Korfund engineers help you solve your vibration problems? An inquiry will not obligate you in any way. Write today.

THE KORFUND COMPANY, INC.
48-36 Thirty-second Place, Long Island City 1, N. Y.
Representatives in Principal Cities



Refrigerating compressors mounted on Korfund Isolators. These machines are installed in a restaurant where prevention of noise and vibration is essential.

Gaskets

No. 4983—A four page folder published by the United States Gasket Co., 1518 Pierce Ave., Camden, N. J., offers construction details and specification data for "Ajax" spiral wound gaskets. Types described include boiler handhole, manhole, tubecap, and other boiler accessory gaskets; self centering gaskets; flange gaskets with steel reinforcing ring; and manhole gaskets with wire guide. These gaskets are available for pressures up to 3500 psi.

Hose Clamp

No. 4984—A four page leaflet issued by the B. F. Goodrich Co., 548 S. Main St., Akron 18, Ohio, describes the "Punch-Lok" galvanized steel safety clamp for banding hose or splicing cable. It is available in both preformed and open end types.

Instruments and Controllers

No. 4985—A new 26 page booklet (45-713) featuring schematic drawings of typical applications of instruments and controllers to industrial control problems such as pressure reducing, rate of flow, and turbine driven compressor control, has been issued by the Hays Corp., 782 E. 8th St., Michigan City, Ind.

Permanent Magnets

No. 4986—Sintered "Alnico" permanent magnets are described in a 20 page bulletin (GEA-3682B) of the General Electric Co., 1 River Rd., Schenectady 5, N. Y. The bulletin describes both the magnetic and mechanical properties of the magnets, which are used in control devices and for many other applications.

Piping Drawing Template

No. 4987—A folder from Eugene Dietzgen Co., 2425 Sheffield Ave., Chicago, Ill., describes a drawing aid for speeding piping layouts—a template. Made of clear plastic for a ⅜ in. equal 1 ft scale, it has 108 machined openings and 60 locating holes for detailing valves and fittings for various pipe sizes. In making a layout, center lines are drawn first and the template is then used for tracing in the various items.

Power Plant Specialties

No. 4988—J. E. Lonergan Co., 2nd and Race Sts, Philadelphia 6, Pa., has issued a reprint of its catalog (500) on power plant specialties, and included with it an information bulletin (501-A) on the company's line of pop safety valves, which are manufactured in accordance with simplified practice recommendations of the National Bureau of Standards.

Pumps at War

No. 4989—A 34 page booklet, amply illustrated with photographs of the many instruments of war which are pump-equipped, has been published by Goulds Pumps, Inc., Fall St., Seneca Falls, N. Y. Pictures and text tell the story of dozens of uses of pumps in the armed forces.

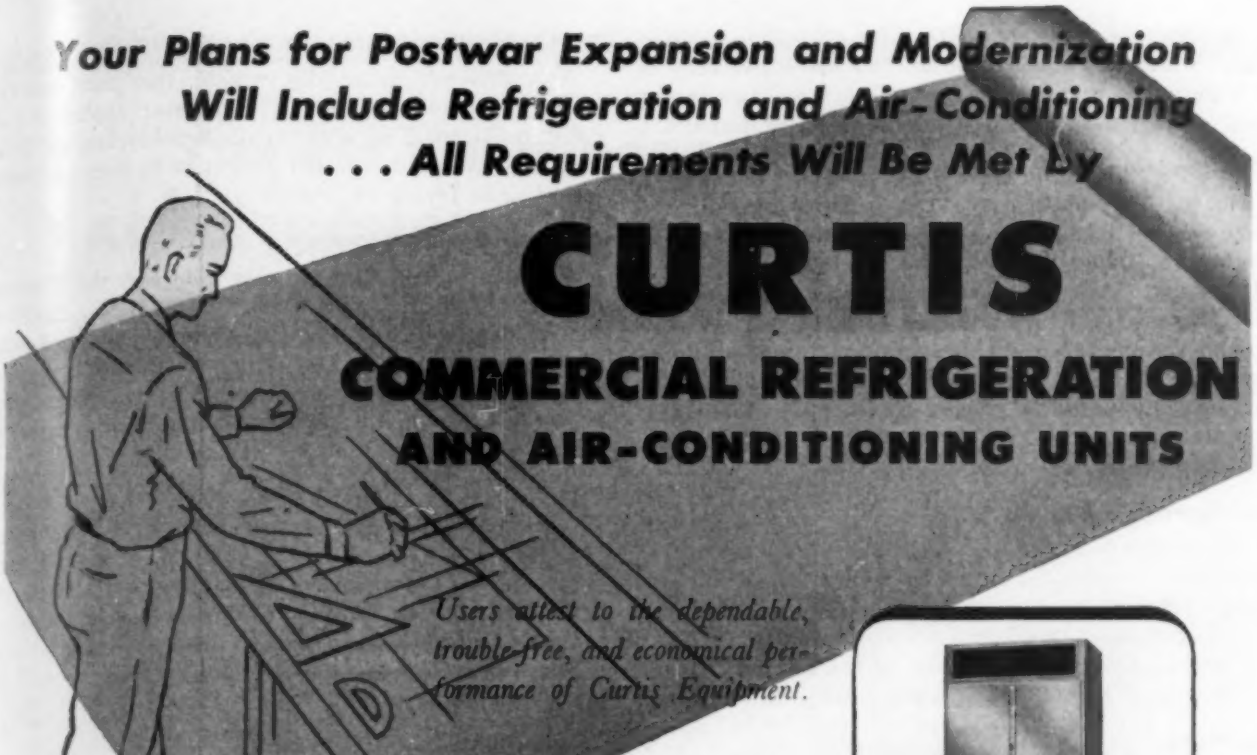
Refrigerant Leak Finder

No. 4990—A four page leaflet has been issued by Western Thermal Equipment Co., 5141 Los Angeles

Your Plans for Postwar Expansion and Modernization Will Include Refrigeration and Air-Conditioning . . . All Requirements Will Be Met by

CURTIS

COMMERCIAL REFRIGERATION AND AIR-CONDITIONING UNITS



Users attest to the dependable, trouble-free, and economical performance of Curtis Equipment.

Just as Curtis is today planning ahead to add new units and to improve and refine many features to keep pace with postwar demand, you, too, should be seriously thinking of the postwar market for air conditioning and refrigeration equipment.

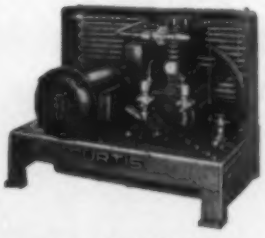
All reports definitely prove the fact that of all industries scheduled for postwar expansion, air conditioning and refrigeration are close to the top. You can get your share of this business by laying a solid foundation *now*, and you can count on Curtis to assist you in every way possible.

Today, all Curtis Units except packaged air-conditioners are available under proper allocation. When Victory is won, the complete Curtis line, improved, up-to-the-minute, and reflecting the experience gained over 91 years, will be ready for you. But — start planning now!

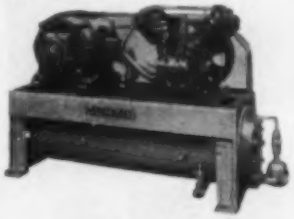
Write for Complete Information

You'll be interested in reading about the possibilities in the field of air conditioning and refrigeration. Write today for Bulletins C-64-E, C-68-C, and C-14-M, covering this interesting and profitable business.

5-hp. Curtis Packaged Air-Conditioner



7½ hp. Curtis Condensing Unit



15-hp. Water-cooled, Shell and Tube Condensing Unit

CURTIS REFRIGERATING MACHINE DIVISION

of Curtis Manufacturing Company

1950 Kienlen Avenue, St. Louis 20, Missouri

CURTIS REFRIGERATION AIR CONDITIONING and COMMERCIAL

R-446

FOR VICTORY BUY MORE U. S. WAR BONDS AND STAMPS

Vista Blvd., Los Angeles 43, Calif., describing "Visoleak," which is a liquid made to stain the entire body of refrigerant in a system dark red. When leakage occurs, this coloration appears around the point of leakage.

Refrigeration Compressors

No. 4991—A bulletin (C-1100) comprising four six-page parts (B11A, B18A, B19A, and B26) and one 14 page part (B20), issued by the Worthington Pump & Machinery Corp., Air Conditioning & Refrigeration Div., Harrison, N. J., describes vertical, two cylinder, single acting enclosed refrigeration compressors of various sizes, and horizontal, double acting, electric driven compressors. Features are carefully illustrated and described, specifications are given, and approximate dimensions are shown.

Refrigeration Supplies

No. 4992—York Corp., Roosevelt Ave., York, Pa., has published 22 new catalog sheets which revise the company's accessory and supply catalog. The revised sheets include price and other data on refrigerants, cold storage doors, insulating materials, valves and fittings for refrigerating plants, brine testing sets, controls, etc.

Resistors

No. 4993—Ward Leonard Electric Co., 37 South St., Mount Vernon, N. Y., has issued a 32 page catalog giving sizes, ratings, and selection data on its line of vitreous enameled resistor units. Also published are new catalog sheets on pushbutton stations and manual speed regulators, and an index and checking list of cancelled bulletins.

Rust Inhibiting Dip

No. 4994—A metal dip which, the manufacturer claims, will not interfere with a later application of paint or lacquer, or with welding, soldering, or brazing, is described in a leaflet published by Special Chemicals Co., 30 Irving Pl., New York 3, N. Y.

Self Lubricating Bearings

No. 4995—A six page circular issued by the Morganite Brush Co., Inc., Long Island City 1, N. Y., describes the company's line of bearings which embody the principle of self lubrication through the use of graphite. Included are reference charts of the physical and mechanical properties of bearings for various applications.

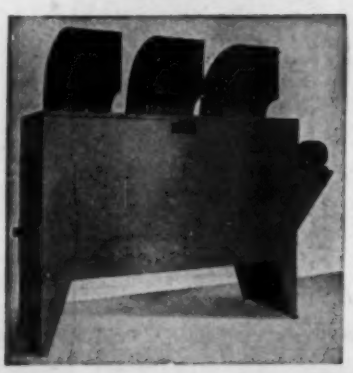
Stokers

No. 4996—An eight page catalog published by the U. S. Machine Corp., Lebanon, Ind., describes and illustrates features of the "Winkler" stokers, which include "Inter-Plan" transmissions and the "Economizer" burner for "assuring maximum combustion efficiency." Specifications for the various models available are presented.

Turbine and Low Lift Pumps

No. 4997—A six page bulletin (AQB400.1) describing oil lubricated turbine pumps, and a six page bulletin (AQB500.1) describing low lift, large capacity pumps, have been published by Fairbanks, Morse & Co., 600 S. Michigan Ave., Chicago 5, Ill. Sizes and capacities of the pumps as well as data on their design and use are given.

Plan Now FOR NEXT SEASON'S HEATING REQUIREMENTS



Now is the time to be planning your heating needs for next season. There is an Airtherm Unit Heater to properly, efficiently heat any plant with a saving in fuel.

AIRTHERM PROPELLER TYPE STEAM UNIT HEATERS

Airtherm Steam Unit Heaters are individually controlled. They provide heat only where you want it, and when you want it. They are available in both vertical delivery and horizontal delivery types for ceiling or wall mount.

AIRTHERM BLOWER TYPE STEAM UNIT HEATERS

A high velocity unit which assures uniform temperature distribution and maximum heat flow effecting savings in both fuel and maintenance cost. This Airtherm Unit is suited to duct installation. Capacities range from 216,000 to 825,000 b.t.u.

Send us your specifications now. Our engineering department is at your service.

AIRTHERM MANUFACTURING COMPANY

711 South Spring Avenue • St. Louis 10, Missouri

You get knowledge and skill with ARMSTRONG'S CONTRACT SERVICE FOR HEAT INSULATION

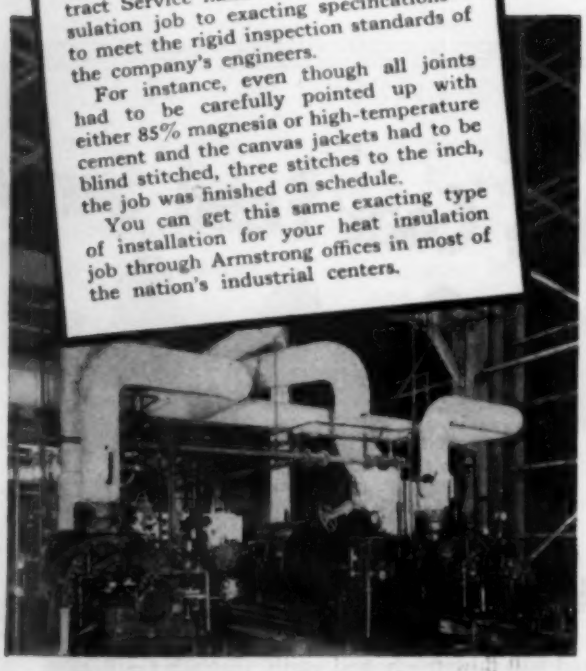
Know-How and Skill Speed Exacting Job

Units #1 and #2 of the Riverside Generating Station of Consolidated Gas Electric Light and Power Company of Baltimore had to be put in service fast to supply power for expanded war industries.

In spite of this necessary speed, the skilled mechanics of Armstrong's Contract Service hand tailored the heat insulation job to exacting specifications—to meet the rigid inspection standards of the company's engineers.

For instance, even though all joints had to be carefully pointed up with either 85% magnesia or high-temperature cement and the canvas jackets had to be blind stitched, three stitches to the inch, the job was finished on schedule.

You can get this same exacting type of installation for your heat insulation job through Armstrong offices in most of the nation's industrial centers.



THE KNOWLEDGE and skill necessary to follow exact insulation specifications are yours when you use Armstrong's Contract Service. That's because Armstrong's engineers, from their many years of varied experience, know how to handle all types of insulation jobs in accordance with modern design practice. But that's only one of the big advantages you gain from this complete service.

Armstrong offers also materials of tested efficiency, skilled mechanics for installation, and close supervision of every phase of the work. The Armstrong organization takes full responsibility for the entire job. For detailed information, write to Armstrong Cork Company, Building Materials Div., 4406 Concord St., Lancaster, Pa.

ARMSTRONG CORK COMPANY

Complete Insulation (A) Contract Service for All temperatures from 300° below zero to 2600°F.

Unit Heaters

No. 4998—With the issuance of a 32 page catalog (6-E) on "Thermolier" unit heaters, the Grinnell Co., Inc., 260 W. Exchange St., Providence 1, R. I., announces that it has resumed production of these units, with copper tubes. The manufacturer claims "12 points of superiority" for these heaters, including an internal cooling leg which permits use of a simple thermostatic trap, pitch of each U-tube for positive and complete drainage of condensate to assure full heating efficiency and elimination of water hammer, and a design making each tube an expansion bend to allow for variations in expansion and contraction. A supplementary device is the "Duotherm" control, which automatically maintains a high temperature when required, and a low temperature during idle plant hours, by remote control.

Viscosity

No. 4999—The Texas Co., 135 E. 42nd St., New York 14, N. Y., has devoted the April 1945 issue of its publication, Lubrication, to an explanation of viscosity. Included in this 10 page magazine are a viscosity index, a viscosity comparison chart, and a viscosity blending chart.

Welding Guide

No. 5000—To help welding students and beginners, Victor Equipment Co., 844 Folsom St., San Francisco 7, Calif., has made available a 46 page illustrated booklet (Form 1) describing how to set up a welding or cutting outfit.

Welding Maintenance

No. 5001—The Lincoln Electric Co., 12818 Coit Rd., Cleveland 1, Ohio, has issued a new edition of its 16 page booklet, 101 Welding Ideas for Low Cost Maintenance. Subject matter of this book remains the same, but the contents have been materially revised.

Preventing Vapor Condensation in Walls

A preliminary report on prevention of vapor condensation in walls and ceilings, of interest chiefly to architects and engineers, has just been published by the Office of Production Research and Development, the WPB announced last month.

The research includes a summary of all work done to date in correcting moisture condensation in walls and ceilings, OPRD said. It was directed by a joint committee from the American Society for Testing Materials, the American Society of Refrigerating Engineers, and the American Society of Heating and Ventilating Engineers. The report, with a comprehensive annotated bibliography, was compiled by the department of engineering research, University of Michigan.

The best methods of preventing inner wall and ceiling condensation so far discovered, the report shows, are as follows:

1) Reduce the humidity inside the building.

2) Make the inner wall structure impermeable and warm enough to be above the dew point of the interior atmosphere.

3) Make the outer wall structure slightly permeable to water vapor.

WELDED All-Steel Worm—All Sizes—All Pitches

★ Crown's complete line of all-steel Coal Feed Screws meets every replacement and production requirement. Produced for both domestic and industrial stokers. Crown Screws are available with right or left hand screws, in all sizes and pitches, tapered or straight, and in combinations of pitches. Uniformly smooth surfaces insure that coal will flow freely and easily through the flights. Because it is all-steel with continuous weld, the Crown Coal Feed Screw guarantees long, continuous operation with full customer satisfaction. Crown is in a position to make prompt delivery on all sizes.

In ordering give complete specifications on size and design.

CROWN IRON WORKS COMPANY

1202 Tyler St., N. E. — Since 1878 — Minneapolis, Minn.

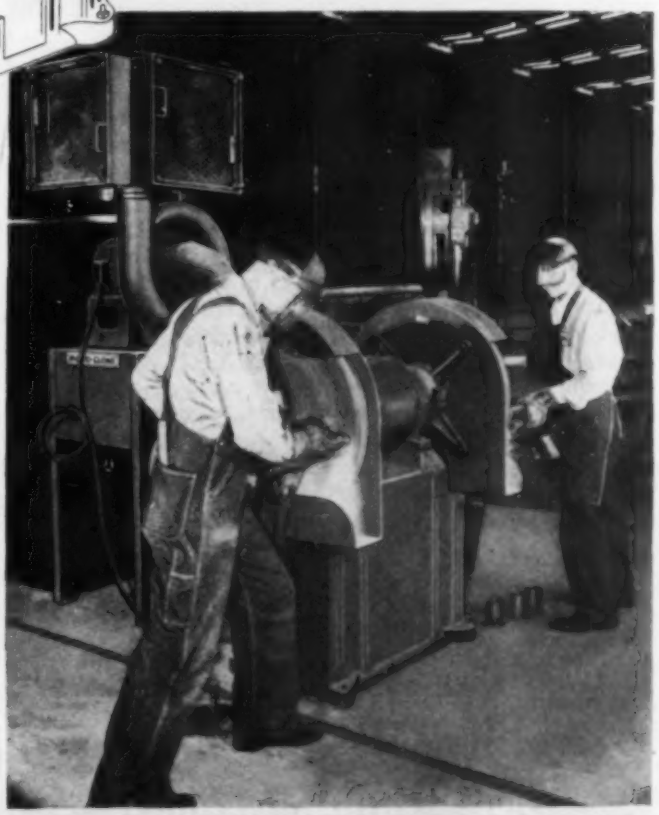
Best Possible DUST CONTROL FOR *all* GRINDING OPERATIONS

This phantom view of the Type D Roto-Clone illustrates the simplicity of exhaust ducts and hood arrangement and the ease with which it collects grinder dust. A Roto-Clone dust control system may be either an individual unit serving a single isolated dust producing operation, or it may be of the central type with main duct and branch connections to a number of dust sources.

ROTO-CLONE OPERATION IS POSITIVE AND TROUBLE-FREE

The proven dynamic principle employed by the Roto-Clone results in a higher percentage of collection of the very small particles and its efficiency is unaffected by changes in air volume or operating speed. Its construction is sturdy and resists the abrasive action of metal dusts, thus assuring long life and freedom from servicing. Send for descriptive Bulletin No. 272.

AMERICAN AIR FILTER CO., INC.
Incorporated
373 CENTRAL AVE., LOUISVILLE 8, KENTUCKY
In Canada: Darling Brothers, Ltd., Montreal, P. Q.



Viscous filter aftercleaners mounted on the Roto-Clone exhaust allow cleaned air to be recirculated to the workroom.

ROTO-CLONE
FOR ALL GRINDING OPERATIONS

BOSSES of the Btu

. . . the insulation experts' skill is your protection against the pitfalls of a poorly applied job.

CORRECT APPLICATION and lasting efficiency of refrigeration insulation are assured by the "Bosses of the Btu". . . men from Johns-Manville's construction forces or J-M Technical Service Units (contractors selected for their records in this field).

And . . . in addition to their skill in application . . . these insulation experts, like leading refrigerating engineers, specify and use Johns-Manville Rock Cork because of its many advantages in refrigerated service. Here are a few of the more essential features:

HIGH MOISTURE RESISTANCE—Made of mineral wool with a waterproof asphaltic binder, Rock Cork is sealed against air and moisture infiltration . . . the cause of most insulation failure. Joints remain tight.

LOW CONDUCTIVITY—Rock Cork's rating is less than 0.33 Btu per sq. ft. per degree F. temp. difference per inch thick, per hour at mean temp. below 100° F.

RESISTANCE TO VERMIN AND BACTERIA—Completely sanitary, Rock Cork is odorless, can't absorb odors, harbor vermin, or support growth of mold and bacteria.

Remember an insulation's performance is only as good as its application!

For details write for brochure DS-555. Johns-Manville, 22 East 40th Street, New York 16, N. Y.

JM JOHNS-MANVILLE
ROCK CORK

• WPB . . . OPA . . . PAW . . . Etc. •

WPB Relaxes Construction Controls

The first step in relaxation of control over construction activities, effected by order L-41 as amended, was announced May 29 by the WPB. Chief changes made by the amended order are the raising of the annual dollar value limits on various types of construction that may be undertaken without WPB authorization and expansion of other exemptions from the provisions of the order. These exemptions permit certain types of construction jobs without WPB authorization and without regard to the annual cost limits. Types of buildings and cost limits are as follows:

1) One family house, including a farmhouse, $1000; two family house, $2000; three family house, $3000; four family house, $4000; and five family house, $5000. These limits apply to repair and maintenance work as well as to alterations and new construction. Cost limit for a house up to and including a five family house was formerly $200.

2) Farm construction, exclusive of farmhouses, $1000. Formerly the $1000 limit included the farmhouses, for which not more than $200 could be spent.

3) An irrigation or drainage system serving more than one farm, $1000. This exemption is the same as in the former order.

4) A hotel, apartment building, or other residence for six or more families, $5000. The cost limit was formerly $1000.

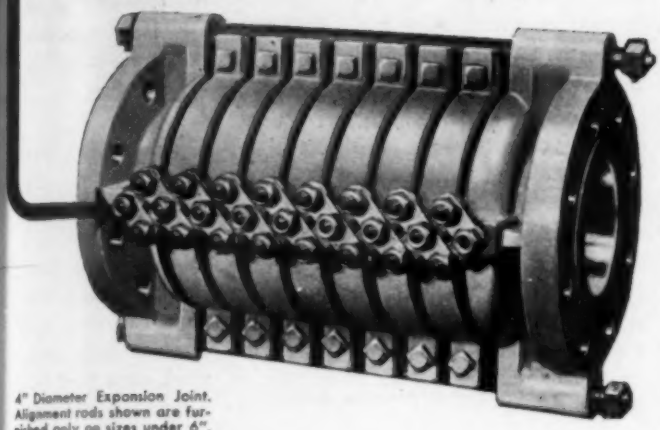
5) An office, bank, store, laundry, garage, restaurant, theater, warehouse or other retail or wholesale service establishment, including a frozen food locker plant, $5000. This category formerly had a cost limit of $200. Warehouses were in a separate category with a $1000 limit, and $200 was the limit for a frozen food locker plant.

The amount of maintenance and repair work that may be done on buildings in categories (4) and (5) is limited. Formerly there was no such limitation.

6) A church, hospital, school, college, United Service Organizations club, public playground for children, a publicly owned building or group of buildings used for public purposes, an orphanage or other building used exclusively for charitable purposes, a military exchange on an Army or Navy reservation, a canal, storm sewer, dam, levee, a jetty or retaining wall needed for shore protection, $10,000. Three former categories with $1000 limits have been combined in this group, and some new types of construction have been added.

7) A factory, plant or other industrial plant, including logging and lumber camps, a bridge, over- or underpass, tunnel, dock, pier, commercial airport, bus terminal, truck terminal operated by a common or contract carrier, a railroad or street railway building or group of buildings, a research laboratory or a pilot plant, $25,000. Formerly, the cost limit for a bridge, over- or underpass, tunnel, dock, pier, airport, bus or truck terminal, railroad or street railway buildings, was $1000. The limit for a factory or plant was $5000,

Something NEW and Unique in Expansion Joints



4" Diameter Expansion Joint. Alignment rods shown are furnished only on sizes under 6".

Zallea Improved Duo-Equalizing* Expansion Joints

The unique feature of the *new* Zallea Improved Duo-Equalizing Packless Expansion Joint is the pantograph linkage. This linkage guarantees equal and *simultaneous* displacement of all corrugations during expansion and contraction of the pipe line. At no time is it possible for one corrugation to move more or less than any other corrugation whether the joint is absorbing its full rated traverse or just a portion of it.

The Result — Longer Life

These new Zallea Expansion Joints are now in service on both steam and process lines in refineries and industrial plants. For complete description and specifications write for Bulletin 45.

*U. S. PAT. PENDING

MADE OF — Copper • Stainless Steels • Corrosion-Resistant Alloys
TRAVERSE — Up to 7½"
FOR PRESSURES — Vacuum to 300 PSI
FOR TEMPERATURES — Sub-Zero to 1600° F.

"Code-Craft"...
ZALLEA BROTHERS & JOHNSON
...EQUIPMENT FOR THE PROCESS INDUSTRIES
816 LOCUST ST. • WILMINGTON 99, DEL.

PETRO
REG. U. S. PAT. OFF.

OIL BURNING SYSTEMS

Petro Class A (Industrial) Equipment is currently available under W.P.B. regulations and ratings.

Petro equipment includes:

DOMESTIC "CONVERSION" BURNERS
1 to 6 gal. per hour

LARGER "LIGHT (No. 3) OIL" BURNERS
general application type
6 to 18 gal. oil per hour

COMBINATION BURNER-GENERATOR UNITS
both steel and C. I. sectional boilers; forced warm air units; and instantaneous water heaters.

INDUSTRIAL OIL BURNERS
Manual - Semi Auto - and Automatic* for either un-heated or pre-heated industrial oils, up to 145 g.p.h. Built-in motor or belt drive.

**When pre-heated oils are burned the Petro Thermal Viscosity system insures consistent maximum combustion efficiency at all firing stages, automatically and reliably.*

Petro Engineering co-operation is still available. Research-development is active. When your post-war activities start, Petro will be ready for you.

OIL IS AMMUNITION USE IT WISELY

Full data on Petro Industrial Burners are in our Catalog—see Sweet's or Domestic Engineering Catalog Files — or we will gladly send copies on request.

PETROLEUM HEAT AND POWER COMPANY
Makers of Good Oil Burning Equipment Since 1903
STAMFORD CONNECTICUT

NOTHING LOCKS LIKE A SPEED NUT

SPEED NUTS are the only fastening devices that provide a COMPENSATING thread lock and a SELF-ENERGIZING spring lock. TWO distinct forces are exerted on the screw, as the SPEED NUT is tightened.

First, a compensating thread lock, the two arched prongs moving inward to engage and lock against the root of the screw thread. These free-acting prongs compensate for tolerance variations, and function perfectly on oversize or undersize screw or bolt threads.

Second, a self-energizing spring lock, created by the compression of the arch in both the prongs and base. The combined forces of thread lock and spring lock definitely eliminate vibration loosening. Literature is available on over 3000 shapes and sizes, for standard or special assemblies.

TINNERMAN PRODUCTS INC.
2018 Fulton Road, Cleveland, Ohio

Speed Nuts
FASTEST THING IN FASTENINGS

except that if the product manufactured was in Schedule A of the former order, the limit was $200. Schedule A does not appear in the amended order. Formerly, construction jobs in plants manufacturing products listed in schedule A could be undertaken without WPB authorization only within an annual cost limit of $200.

8) Any other kind of unit, $1000. Cost limit for this category was formerly $200.

Twenty-three special kinds of construction may be undertaken without WPB permission regardless of annual cost limits. These exemptions are, in general, the same as formerly appeared in the order, its schedule B and interpretations and directions.

Other important changes in exemptions are:

The exemption for maintenance and repair work has been changed to limit the amount of work on (1) hotels, apartment buildings, and other residences for six or more families, and (2) offices, banks, stores, and other retail or wholesale service establishments that may be done without authorization. In any year, the amount spent on repairs on such structures may not exceed 20 cents for each square foot of gross floor area. In addition, the owner may use up part or all of his $5000 exemption for repairs, but the allowance for new construction must be reduced accordingly. Repair and maintenance work costing above the permitted amount requires WPB authorization.

The exemption for the installation of equipment (formerly Direction 2) has been broadened to permit installation or erection of equipment outside buildings. However, installation of service equipment is permitted

WHITLOCK
FLASH-TYPE DEAERATING FEED WATER HEATING SYSTEM

The Whitlock Flash-type Deaerating Feed Water Heating System for reducing gas inclusions has been designed for proper deaeration. The system utilizes bleed or exhaust steam and the amount of flash or "boil-off" can be varied. Normal oxygen concentrations consume iron very rapidly and the Whitlock system soon pays for itself by preventing the corrosion of boiler tubes, carrying lines, and other equipment.

Flexibility, easy maintenance and ability to accept steam at various points at different pressures make the Whitlock system . . . with simple construction and *no internal complexities* . . . the optimum equipment for boilers up to 2000 HP. Let our engineers analyze your requirements.

Write for Bulletin 645 covering Whitlock Power Plant Equipment.

THE WHITLOCK MANUFACTURING CO.
44 South Street, Elmwood, Hartford 1, Conn.
New York, Boston, Chicago, Philadelphia, Detroit, Richmond
In Canada: Darling Brothers, Ltd., Montreal

50,000 to 10,000,000 B.t.u. with WECO-N.G.E. Series F600

GAS BURNERS. For use in heating heating boilers, power boilers—in any metal firebox or sectional boiler.

Adaptable to any firebox shape or size.

Handles various gas pressures and effects low draft loss.

The Series F600 Burner operates on straight natural gas and mixed gas to 800 B.t.u. Gives perfect horizontal distribution. Full automatic controls—that operate properly —can be easily applied. *Write for F600 Bulletin.*

THE WEBSTER ENGINEERING CO.

TULSA —DIVISION OF— **OKLAHOMA**

Surface Combustion . . . . . Toledo, Ohio

PATENTED

YOUR OWN REFRIGERATION PLANT WILL GIVE MORE PRODUCTION WHEN YOU INSTALL THE NIAGARA Duo-Pass AERO CONDENSER

● Reduced compressor head pressure increases your refrigeration capacity and the NIAGARA DUO-PASS AERO CONDENSER provides a sure method of constant operation at lower head pressure. Because, by the evaporative cooling principle, Niagara Duo-Pass Aero Condenser removes 1000 BTU per pound of water evaporated, you save cooling water costs amounting to thousands of dollars.

These gains are permanent because the patented NIAGARA "Duo-Pass" feature lowers the condensing temperatures to the point where no scale or precipitate can be deposited on the condenser tubes to reduce its capacity.

Get Bulletins 91 & 93 for full information.

NIAGARA BLOWER COMPANY

Over 30 Years of Service in Industrial Air Engineering

Dept. HP-65, 6 E. 45th St. NEW YORK 17, N. Y.

Field Engineering Offices in Principal Cities

INDUSTRIAL COOLING HEATING • DRYING **NIAGARA** HUMIDIFYING • AIR ENGINEERING EQUPT.

Janette
Blower Wheels
5 to 12 in.
These Illustrations Show the Patented Construction of a Janette Wheel.
The blades are formed in pairs for rigidity. The blade slots in the steel discs are die cut to ensure exact spacing of the blades. The hub is riveted to the back plate; then the blades are inserted into the slots. After the blades are spot welded to the back plate the tips are pressed thru the slots of the inlet disc, then rolled down against the disc.
The Inherent Spring of the Blades Keeps Them Tight.
Because of This Construction, Janette Wheels have given over 19 years of universal satisfaction to internationally known manufacturers of coal stokers, blowers, ventilating equipment, air cooled engines, oil burners, superchargers,, dust collectors, drying and fire detection apparatus. It Will Pay You to Give Janette Blower Wheels a Trial!
May We Send Literature?
Janette Manufacturing Company
556 W. Monroe St. Chicago 6, Ill.

only when the equipment was obtained on a specific application, such as WPB-541.

Limitations on minor capital additions have been relaxed to permit industries manufacturing products formerly listed on schedule A and all organizations covered by CMP regulation 5A to take advantage of the exemption on minor capital additions. Formerly these industries and organizations were excluded from the exemption.

More Amendments to Fuel Oil Ration Order

Following is information on two amendments to the OPA's fuel oil rationing order Rev. RO 11:

Amendment 57, effective May 8

PREVIOUS REGULATIONS

A ration may not be issued or used for surfacing or maintaining roads or laying dust on roads.

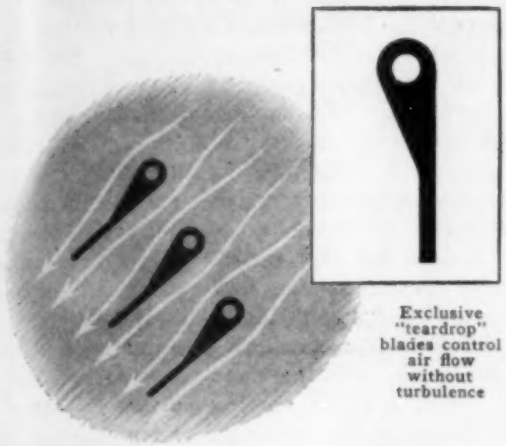
CHANGE AND REASON FOR CHANGE

1) To permit the issuance and use of a fuel oil ration for these purposes, except in the states of Washington and Oregon, only if (a) the fuel to be used is that commonly known as "Slow Curing Road Oil No. 1, 2, 3, 4 or 5" (SC-1, SC-2, SC-3, SC-4 or SC-5) and (b) the applicant is a federal or state agency, a political subdivision of a state government or a person, pursuant to a contract with any of these, performing the work for which the ration is sought.

2) To prohibit the issuance or use of a fuel oil ration for the production of paving material or dust palliatives unless the PAW has granted the applicant a currently valid exception to this restriction under petroleum distribution order No. 13. However, in all states within the limitation area except Washington and Oregon a

How to make a SISSY
OF YOUR TOUGHEST
STEAM REDUCTION PROBLEM
Get acquainted with K & M Type 479 . . . the internal pilot operated pressure regulating and reducing valve that is a veteran of many a difficult installation. You'll get very close constant control at high and low pressures, regardless of inlet variations. You'll get freedom from chattering and excessive wire drawing on low loads. You'll get tight closure in dead-end service.
Type 479 is built for initial pressures to 600 lbs.; reduced pressures from 2 lbs. to 80% of inlet. There are 66 years of steam control experience built into Type 479. You can count on getting long years of cost-saving performance out of it. Furnished with bodies of standard or extra heavy semi-steel or cast steel; trim of bronze, monel or 18-8 stainless steel; sizes 2" to 10", flanged connections.
Our Engineering Department is ready to work with you . . . without obligation . . . without delay.
KIELEY & MUELLER, INC.
MANUFACTURERS OF PRESSURE AND LEVEL CONTROLS SINCE 1879
2015 43rd St. North Bergen, N. J.
66 YEARS OF CONTROL PROGRESS

Quiet as a Whisper



Exclusive "teardrop" blades control air flow without turbulence

streamlined BLADES handle high-velocity air without grille noise

In buildings where air distribution requires high velocities, the modern answer is

Waterloo AIR DIFFUSERS

The exclusive *streamlined* blades on Waterloo registers and grilles direct the flow of air without noise or turbulence. And because each blade is individually adjustable, the air flow can be channeled in 1-2-3 or 4 directions at the same time—to fit the individual requirements of each room. Definite advantages, that make it worth while to specify Waterloo. And, post-war, Waterloo "grilles of the future" will be still further ahead of the parade.

Waterloo REGISTER CO.

Established 1902

Waterloo, Iowa Seattle, Wash.

Representatives in all principal cities

Soliciting
POST-WAR BUSINESS
Send Specifications Now...Insure Quick Shipment when Priorities are Lifted

FACTS OF L-H FORCED DRAFT COOLING TOWERS

Fans blow air in at base of tower through fan openings; out top through eliminators. Airflow is counter-current to falling spray water.

Walls are made of two thicknesses of 1 x 6 tongued and grooved sheathing, made in panels; liberal air space between water-tight interior and exterior sheathing.

Driving units at base of tower permit quick inspection and adjustment of fan assembly.

Spray Distribution

Water is uniformly distributed by trough distributing system or spray nozzles.

L-H removable filling gives uniform distribution of water and air.

General Data

Teco split ring timber connectors develop 100% working stress of members. Towers constructed of Heart Redwood, or Tidewater Red Cypress. Equipped with spray eliminator system at top, zigzag pattern of three tiers. Drift loss amounts to less than .2 of 1%.

Write for: Catalog 440-A

Lilie-Hoffmann
COOLING TOWERS, INC.
Manufacturers of All Types of Water Cooling Towers
GENERAL OFFICE: 4239 DUNCAN AVE., ST. LOUIS 10, MO.
PLANTS AT ST. LOUIS, MO. AND PLAINVIEW, TEXAS

"COMMERCIAL"

STEEL FURNACE HEADS
RADIATOR CRESCENTS
FLUE COLLARS

All "Commercial" parts for furnaces are formed cold and in one piece, without cracks or folds. From this method of manufacture, smooth flanges result, which are insurance against leaks. The dimensions are accurate and do not vary with each head or flange and fast, economical assembly is possible.

Send us your inquiries. We can furnish heads in many dimensions and flange lengths.

THE COMMERCIAL SHEARING & STAMPING CO.
Youngstown, Ohio

ration may be issued and used to acquire the above mentioned "Slow Curing Road Oil" for making such products without approval from the PAW.

These changes are made at the request of the PAW to conform revised ration order 11 to the provisions of petroleum directives No. 72 and No. 80.

Amendment 58, effective May 23

I. PREVIOUS REGULATIONS

The regulations generally prohibit the issuance of a ration for fuel oil burning cooking or water heating equipment if the applicant has a standby facility.

CHANGE AND REASON FOR CHANGE

To permit the issuance of a ration for domestic cooking and hot water for the period May 1 through September 30 of each year, even though the applicant has a standby facility. Similar provision was made for the last two summers.

II. PREVIOUS REGULATIONS

Upon the expiration of certain rations the consumers are required to surrender to the board the coupon sheets issued for the ration. No such requirement exists for consumers who have ration bank accounts.

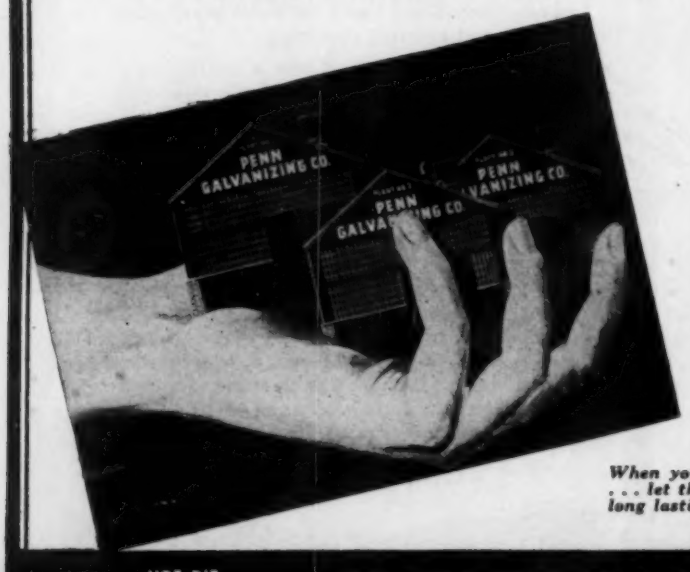
CHANGE AND REASON FOR CHANGE

To require ration banking consumers whose rations have expired to pay their ration debts and surrender to the board a check for the balance of the expired ration within 20 days after the ration expires.

III

To avoid any possible confusion with respect to the issuance of additional rations for consumers using residual oil, it is explicitly stated that such additional rations shall be issued only for the 1944-45 heating year.

3 PLANTS TO SERVE YOU!



AT PENN GALVANIZING you have the facilities of 3 plants working 24 hours a day, 7 days a week, to take care of your demands for QUALITY HOT DIP GALVANIZING of your iron and steel products. Furthermore, you are assured of the PENNizing process as perfected by PENN through long experimentation.

When you need QUALITY HOT DIP GALVANIZING in a hurry . . . let the NATION'S LARGEST do the job . . . you will get the long lasting protection at the most economical cost.

HOT DIP GALVANIZING
•
GALVANIZED IRON AND STEEL PRODUCTS FURNISHED

PENN GALVANIZING CO.
"the Nation's Largest"

PICKLING AND PAINTING
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PICKLED AND PAINTED IRON AND STEEL PRODUCTS FURNISHED

Gen. Offices: 2201 E. Tioga Street, Philadelphia, Pa.
PLANTS: No. 1, 2201 E. Tioga St. - No. 2, 2400 E. Tioga St. - No. 3, 2548 N. Sepviva St.

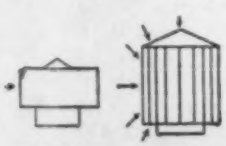
Breidert Air-X-Hauster CHIMNEY TOP

The greatest scientific improvement in Ventilators in over 50 years

TYPE B-2 CHIMNEY TOP

Eliminates smoking fireplaces caused by down-draft

By stopping all down-drafts (interior negative pressure excepted), a Breidert Air-X-Hauster on the chimney absolutely prevents the fireplace from smoking and damaging furnishings. *It provides positive "draw" regardless of wind direction!* Scientifically designed to convert *any* wind current into a powerful suction force, the Breidert remains stationary, has no moving parts. Successfully in use in all parts of the country.



Old Method — Breidert Method

TESTED AND CERTIFIED . . . Thoroughly tested by Smith, Emery & Co. (Pacific Coast branch, Pittsburgh Testing Laboratories) with wind blowing at *all* angles, the Breidert's amazingly high capacities are fully certified.

Breidert Air-X-Hauster Roof Ventilators and Vent Flue Caps

The remarkable ability of the Breidert Air-X-Hauster to provide positive ventilation no matter which way the wind blows, has been proved in thousands of installations throughout the country. Properly installed, the Breidert has *never* failed to fully meet every claim made for it!

TYPE A FOR ROOF — TYPE B VENTILATING — VENT FLUE CAP

WRITE FOR FREE ENGINEERING DATA BOOK . . . containing specifications and installation data, certified capacities, etc. Address Dept. S.

G. C. BREIDERT CO.

634 South Spring St., Los Angeles 14, California

REPRESENTATIVES LOCATED IN PRINCIPAL CITIES OF THE U. S.

Refrigeration Service Engineers . . . .

PERFORMING OUTSTANDING MAINTENANCE JOB

Today, in towns all over America refrigeration service engineers are doing an outstanding maintenance job of keeping refrigerated display cases, ice cream cabinets, food storage lockers and the countless other applications of refrigeration running smoothly and efficiently.

On call the refrigeration service engineer performs his task, ofttimes while the city sleeps. Thousands of dollars he has saved retailers, countless thousands of pounds of precious food he has prevented from spoiling.

These men rely on A-P DEPENDABLE Refrigeration Controls. They use A-P DEPENDABLE Refrigeration Controls to help them perform their important task. As many of them write, "I use a lot of A-P Controls and never had one fail me yet."

AUTOMATIC PRODUCTS COMPANY
2460 North Thirty-Second Street
Milwaukee 10, Wisconsin
Export Dept., 13 East 40th Street, New York 16, N. Y.

A-P Model 205 Thermostatic Expansion Valve. Capacity up to 1 ton Freon.

DEPENDABLE *Refrigerant Valves*

Stocked and Sold by Good Refrigeration Jobbers Everywhere. Recommended and Installed by Leading Refrigeration Service Engineers.

The General Says

ATTENTION

Write today for the complete information which General Blower Co. has prepared for you regarding

GENERAL MULTIBLADE EXHAUSTERS

Ask for Portfolio SC-101—H.P.A.

GENERAL BLOWER COMPANY

Producers of Air Moving Equipment

401 North Peoria St. Chicago 22, Illinois

Fuel Oil Conservation Still Vital

Increasing military requirements, together with transportation difficulties in the Pacific northwest, make it necessary that present restrictions on and conservation of civilian fuel oil supplies in that area be continued until the war in the Pacific is won, Deputy Petroleum Administrator Ralph K. Davies said June 1.

"The end of the war in Europe has not relieved the problem of either home heating (distillate) fuel oil consumers or industrial (residual) fuel oil users in Washington, Oregon, and western Idaho," Mr. Davies said. "We hope to have as much home heating oil available for northwest consumers next winter as they received during the last heating season, but there will be no more available for civilians even though total production will be higher in the coming months than at any period in the past. The condition with reference to industrial fuel oil is even more serious because the pinch is continual, rather than seasonal," he stated.

Mr. Davies said that although the Pacific northwest is the closest area in the United States to the scene of the Pacific war, PAW hopes that civilian consumers in the northwest will not have to shoulder greater restrictions in fuel oil supplies than consumers in other areas far removed from the west coast.

Heating Limitation Orders Withdrawn

Several limitation orders covering heating equipment —oil burners (L-74), coal stokers (L-75), floor and wall furnaces (L-173), and cast iron boilers (L-187)— were revoked May 11 by the WPB. Production and delivery of products controlled by these orders are still

Permanent, Postwar

SALESMEN'S OPPORTUNITY

OPEN NOW

Four or five men with heating or combustion backgrounds are wanted at once by an equipment manufacturer for trade-contact marketing work in established territories. Selling ability and experience are essential. Knowledge of, and liking for, mechanics or engineering will be very helpful in this work.

The type of man most likely to be successful in this particular work could be a technical school graduate who has had a couple of years or more experience in selling heating equipment, power plant specialties, combustion control equipment, stokers or oil burners to wholesale distributors and, or, installing contractors. However, a college degree is not a first essential. A practical working knowledge and some experience in heating and power plant work coupled with sales ability is what the job requires.

The Company that wants these men is old and well established in this field. It is respected, progressive, well financed, and is currently planning further expansion and progress in its products and markets. These plans definitely include aggressive promotion and marketing to re-inforce the personal efforts of its representatives.

The line is already well known to the trade and the public and has an enviable performance record and users' satisfaction of many years standing. This line is now in process of further refinement and expansion. Its market is international and growing.

All the men now in this company's marketing division have read this advertisement and agree it is a fair and conservative outline of an opportunity. It is a competitive field, and the work will be varied and interesting, but not attractive to anyone looking for a "pushover".

Every response to this advertisement will receive executive consideration. No inquiries will be made until after an interview has provided a basis for such inquiry and the applicant has authorized it. Interviews can be arranged at practically any time and place, and will be requested on the basis of personal and business experience data in the responses received. It is requested that such data be complete and specific enough to provide an informative outline.

Box 469-A

Heating, Piping & Air Conditioning

6 North Michigan Avenue

Chicago 2, Illinois

JOHN ZINK
Series "V" Burner

Venturi Type . . . .

This John Zink UP-SHOT GAS BURNER is absolutely noiseless. Especially designed for heating boilers, where noise must be kept to an absolute minimum. Ideal for installations in hospitals, churches, apartments, etc.

•

Easily Installed—Do not require fire-brick settings.—Do not require fire-brick to hold ignition on the burner heads.

- WIDE RANGE OF CAPACITY—Operating range is from 5" W.C. to 3 lbs. gauge pressure.
- HIGH EFFICIENCY—Full on and off operation.
- NO VIBRATION or PUFFING.
- Low First Cost.
- Safety pilots can be supplied when required.

Write for descriptive literature

•

John Zink Company

4401 South Peoria

TULSA, OKLAHOMA

New York - Los Angeles - Detroit - San Francisco - St. Louis

Extra Long Taper of the new RIDGID LonGriP Pipe Reamer

means safe, easy reaming of burr only

• It cuts the burr out clean as a whistle—but it doesn't gouge, thin or split the pipe. Quick easy feather-light strokes, no effort at all. The trick is in the extra long taper—it saves you work *and pipe.* Complete with ratchet handle—or you may buy *reamer unit* alone for use in your RIDGID No. 00R threader handle. War demand exceeds our vastly increased output—we're doing our best to make deliveries to your Supply House. Keep asking.

Reamer unit fits No. 00R ratchet threader handle.

RIDGID

WORK-SAVER PIPE TOOLS

THE RIDGE TOOL COMPANY · ELYRIA, OHIO, U. S. A.

WILLIAMS

SUPERIOR DROP-FORGED TOOLS

"VULCAN SUPERIOR"

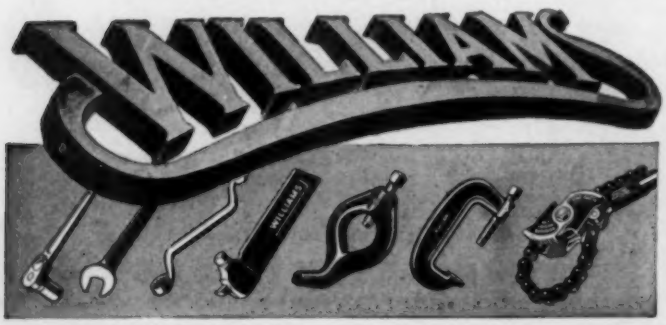
CHAIN PIPE VISES

Above: "VULCAN SUPERIOR", with reversible jaws and adjusting handle on top. 2 sizes for pipe 1/8 to 4-1/2 inches.

At right: "VULCAN". 4 sizes for pipe 1/8 to 8 inches.

● Williams "Vulcan Superior" is an improved vise featuring "over-head" adjustment handle ... making it easier and faster to use. Jaws are reversible providing double the service of conventional vises. It has larger capacity too. Each vise takes pipe 1/2" larger than other chain pipe vises of similar size. Like all Williams tools it is fully guaranteed. Sold by Industrial, Plumbing & Oil Field Distributors everywhere.

J. H. WILLIAMS & CO., BUFFALO 7, N. Y.



subject to other applicable regulations and orders, WPB said.

Order L-74 limited production of domestic-type (class B) oil burners to quotas established by WPB on a quarterly basis. Sale and installation of domestic type oil burners was permitted only for replacement and to the extent permitted by the PAW and the OPA. PAW's petroleum distribution order 13 and OPA's fuel oil rationing restrictions are still in force, WPB officials pointed out.

Order L-75, which covered coal stokers with a grate area of 36 sq ft or less, also limited production to quotas established by WPB on a quarterly basis. The steel order, M-126, still prohibits the use of stainless steel in coal stokers, WPB said.

Both L-74 and L-75 were originally issued in April 1942, to effect savings in iron, steel, fractional horsepower motors and other critical items. L-74 was also designed to save fuel oil.

Order L-173 permitted production of floor and wall furnaces only for the military services, and upon specific WPB authorization for civilian use. As originally issued in August 1942, the order prohibited any production for civilian use. It was designed to save steel.

Order L-187 limited production of cast iron boilers to 25 per cent per quarter of manufacturers' 1940 output. Increased production quotas were permitted by specific WPB authorization. The order as originally issued in November 1942 permitted manufacture only for the military and for hospitals.

Extended Surface Limitation Order Revoked

With the revocation of limitation order L-107 last

EFFICIENT

ECONOMICAL

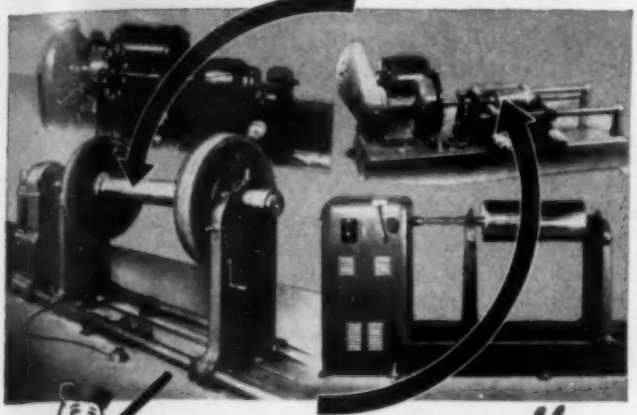
De Luxe type WK Pressure Actuated Water Regulating Valves for Freon, Sulphur or Methyl, are pilot operated, modulating. Standard adjustable opening range from 50 to 150 lbs. Factory set to open at 90 pounds. Precision engineering and individual testing for low cost, satisfactory performance. Available in sizes of ¾ to 2 inches FPT. Simple adjustment—easily serviced.

Other sizes and types are also available.

Electrimatic

2100 INDIANA AVE. CHICAGO 16, ILL.

For rotating bodies Large



or Small

NOW . . . A Complete Line of BEAR *DY-NAMIC* BALANCING MACHINES DRIVE OUT THE "WOBBLIES"

Quicker • Easier • at Lower Cost!

REDUCE WEAR

MINIMIZE VIBRATION

ELIMINATE NOISE

INCREASE EFFICIENCY

CUT MAINTENANCE

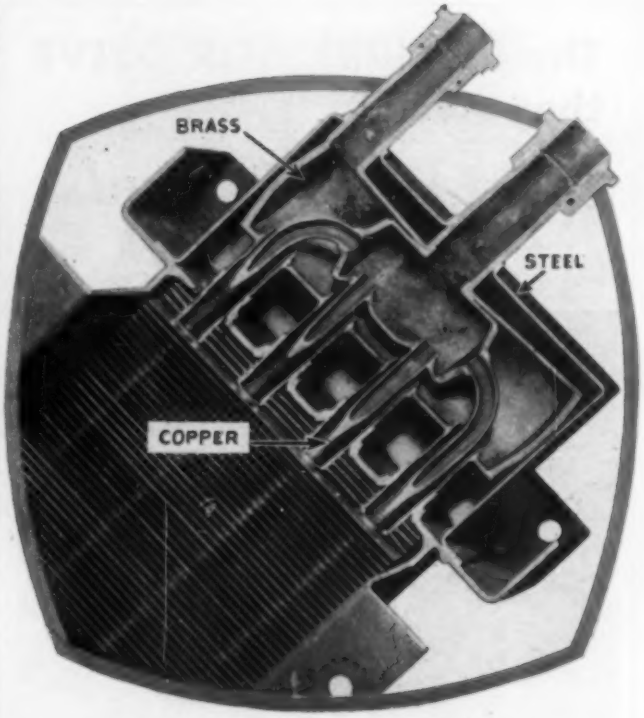
Dy-Namic Balancing of all rotating parts, from tiny armatures to heavy railroad car wheels, is recognized today as never before as *essential* to longer machine life and more efficient operation. Bear's new, but thoroughly proven Balancing Technique, and lower cost, easier-to-operate Balancing Machines, now make Dy-Namic Balancing of *all* rotating parts a *fast, simple* and *economical* operation.

Write for FREE BEAR INDUSTRIAL BALANCING BULLETIN, containing complete information on this essential equipment. It explains the Bear Dy-Namic Balancing Principle which makes Dy-Namic Balancing so simple that operators can be trained in a few hours. Illustrates and describes Bear's complete line of machines for balancing every rotating part from 4 oz. to 4000 lbs. Tells how you can cut the time and cost of Dy-Namic Balancing.

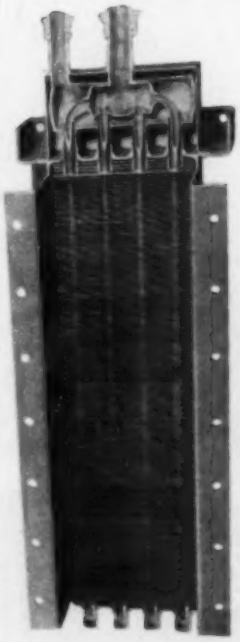
BEAR MFG. CO., Dept. HPV,
Rock Island, Illinois

1186

BEAR
DY-NAMIC BALANCING MACHINES



EASY-FLO —just right for fabricating thin-gauge metals



The Heater shown is typical of a wide variety of parts now fabricated from thin-gauge metals by brazing with EASY-FLO. The reason is that brazing with this low-temperature silver alloy meets the physical and economic requirement of this work.

From the physical angle, EASY-FLO brazed assemblies are as strong, as liquid and gas tight, as able to stand severe stresses and strains as solid metal. And EASY-FLO's low working temperature makes it possible to guard against heat damage to thin metals.

From the economic standpoint, EASY-FLO brazed fabrication means fast production and ample savings in man-hours and machine-hours.

GET EASY-FLO FACTS NOW IN BULLETIN 12-A

Now is the time to check the possibilities of EASY-FLO brazing for fast, economical production on your peace-time metal joining. Write for Bulletin 12-A today.

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82 FULTON ST., NEW YORK 7, N. Y.
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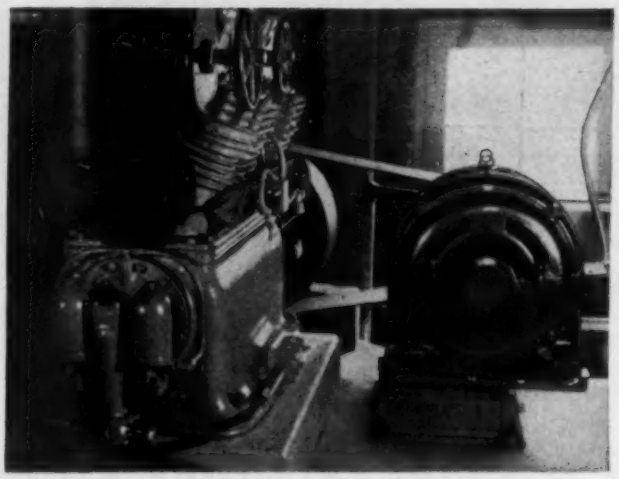
The COMPRESSOR DRIVE that gives

RELIABILITY and LONG LIFE



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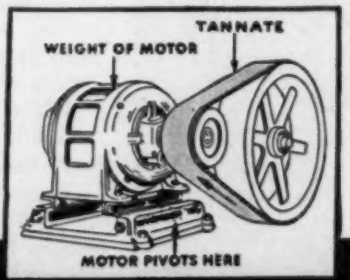
on 100 H. P. motor operating compressor for air conditioning system. It is still running with perfect satisfaction.

For a compressor drive that will give dependable, trouble-free service over a long period . . . select a Tannate-Rockwood Short Center Drive.

The Rockwood pivoted motor base provides a simple means of securing *correct belt tension.* This is the important factor in assuring maintenance of high efficiencies at peak loads.

The great strength, flexibility, and endurance of the Tannate Leather Belt results in long life with almost no maintenance. Rhoads Engineering Service is available to help you select the proper drives.



RHOADS
Tannate-Rockwood
SHORT CENTER DRIVE

J. E. RHOADS & SONS
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month, delivery of light weight, extended surface heating equipment is no longer restricted to rated orders, repair orders, or orders accepted by producers prior to August 7, 1943, the WPB has reported. Production and delivery is still governed by other applicable orders and regulations of WPB, however, such as the controlled material plan and priorities regulations. Items affected by the revocation are unit heaters, unit ventilators, copper convectors, and blast heating coils. This action is in keeping with WPB's policy of removing all controls that do not interfere with the prosecution of the war.

The limitation order, as originally issued June 13, 1942, prohibited delivery of the equipment except to the armed services and upon specific authorization, as a means of conserving scarce materials.

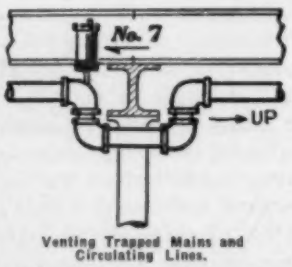
Schedule 1 to L-107 was issued subsequently to establish certain simplified practices in the manufacture of specific items of this equipment. This schedule was revoked November 16, 1944.

L-107 was amended later to limit delivery to approved orders bearing preference ratings of AA-5 or better and specific delivery dates.

Refrigeration and Air Conditioning Orders Revoked

Revocation of limitation order L-126, which set forth required specifications and schedules for specified items of industrial and commercial refrigeration and air conditioning machinery and equipment, and schedules I, III, and VI of the order, was announced last month by the WPB.

Revocation of limitation order L-38, covering produc-



Venting Trapped Mains and Circulating Lines.

Circulation Troubles?

Don't fight air pockets or traps in hot or cold circulating lines. "Get that air out of there" *and keep it out* simply by installing the No. 7 Maid-O'-Mist Automatic Air Vent. This reliable air vent has a self-closing float-controlled valve and is designed especially for circulating pipe lines, convector radiators, unit heaters, cooling manifolds, tanks, diesel engines, or any other application where air pockets or traps retard the free circulation of liquids. Now available in bright brass finish. For pressures up to 75 pounds.

APPROVED FOR NAVY, MARITIME COMMISSION AND ARMY USE

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AUTOMATIC HUMIDIFIERS FOR ALL TYPES OF HEATING SYSTEMS
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The RECESSED BRASS SEAT

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JEFFERSON UNION

is cut from seamless drawn tubing
—free from all casting defects—
sound and uniform always!

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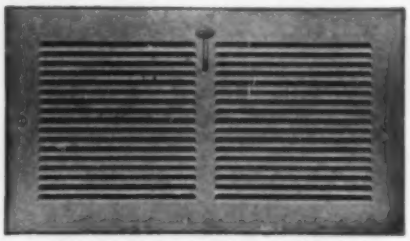

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ADJUSTABLE

AIR DIRECTIONAL REGISTERS

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Auer offers a complete line of floor, base, and wall registers and return faces, for gravity or air conditioning systems—including all air directional types. We also make flat metal grilles. Ask for Auer Register Book—or special Grille Catalog "G."

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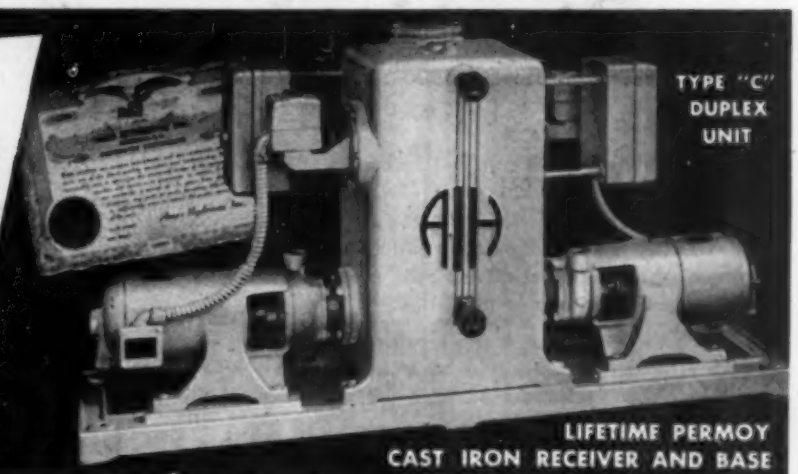
AMES
HYDROVAC
CONDENSATE RETURN UNITS



TYPE "C" DUPLEX UNIT

LIFETIME PERMOY CAST IRON RECEIVER AND BASE

SUPERIORITY GUARANTEED!

Engineering skill of the highest order combined with metals and other materials of topnotch quality account for the unusual 3-year Wear-Proof guarantee that goes with HYDROVAC UNITS. Note, too, these special features.

- MOTOR VENTILATION Pat. Applied For
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- EXTRA LARGE SHIELDED BEARINGS
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- HYDRAULIC BALANCE REDUCES THRUST
- NEOPRENE WATER SLINGER

PUMPS BY WORTHINGTON

Superior in Every Way

(1) High Efficiency. (2) Beauty of Design. (3) Lifelong Durability. (4) Negligible Maintenance Cost.

Write for Bulletin No. 200-A showing Consultants' Specification Form, Standard Ratings and Blueprint

Also ask for Bulletin No. 100-A on complete line of HYDROVAC VACUUM RETURN UNITS

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HYDROVAC
INC.
290 SCHOLES STREET
BROOKLYN 6, N. Y.

tion and delivery of industrial and commercial refrigerating and air conditioning machinery and equipment, was also announced. Also revoked were directions 1, 2, and 3 to L-38, covering respectively evaporative coolers for civilian use in desert areas, mechanically refrigerated farm milk coolers, and refrigerated display cases.

WPB emphasized that the revocation of these orders must not be considered as giving any assurance that all the materials required to produce a product will be available.

Heating and Plumbing Tank Order Revoked

Order L-199, which controlled the manufacture of range boilers and hot water storage tanks (plumbing and heating tanks), was revoked last month by the WPB. Production and distribution of these items are still subject to all other applicable orders and regulations, WPB said.

L-199, as last amended in January 1945, restricted the use of copper, stainless steel, and monel metal; limited production to the sizes and designs specified in schedule A (black iron or galvanized range boilers), schedule B (porcelain enameled range boilers), and schedule C (expansion tanks), and set up production quotas.

Refrigeration Repair Parts Order Amended

Certain refrigeration repair parts have been added to the list of items that may not be bought by repairmen with the AA-3 rating assigned by controlled materials plan regulation 9-A, the WPB announced last month.

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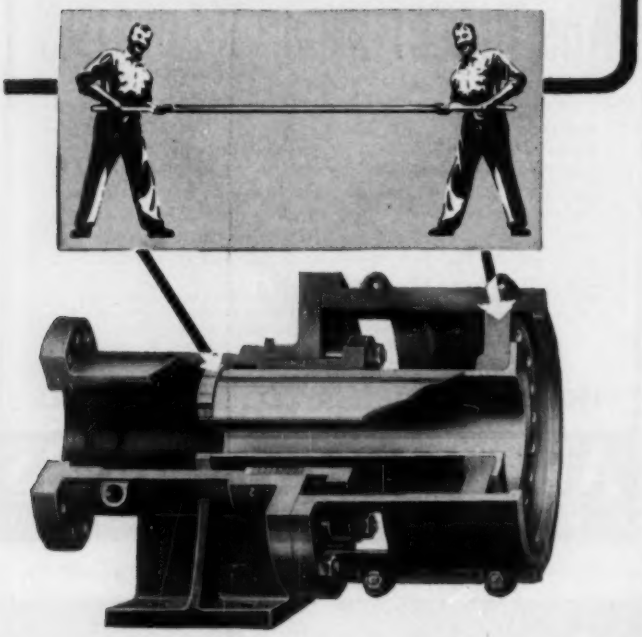
INTERNALLY-EXTERNALLY GUIDED

EXPANSION JOINTS

Keeps the slip in perfect alignment because they are guided at BOTH ends



Slip Moves Through Packing Without Binding

Try to hold a pole at one end and keep it level. Then have someone hold the other end, and note the difference. That's precisely why the ADSCO Internally-Externally Guided Expansion Joint stays in alignment —why the slip moves through the packing space without undue pressure or distortion.

This protection against slip scoring is the reason why the intervals between repacking are few and far between when you use ADSCO Internally-Externally Guided Expansion Joints.

Install them on high or low pressure pipe lines, hot water, fuel oil, gasoline or process—wherever the most complete form of guiding is required. Write for Bulletin No. 35-20BHP describing ADSCO Internally-Externally Guided Expansion Joints in sizes from ¼" up with 4" or longer traverses.

WRITE FOR YOUR COPY OF CATALOG DESCRIBING COMPLETE LINE OF ADSCO PRODUCTS

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NORTH TONAWANDA NEW YORK

Makers of "UP-TO-DATE" Steam Line Equipment For Over 65 Years

FEATURES – *(Turbine Type)*

Water-cooled head bearings • Choice of oil or water lubrication • Double Bearings in each bowl • Fully-Enclosed impellers • Double Seal impellers.

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Capacities—10 to 220,000 gallons per minute

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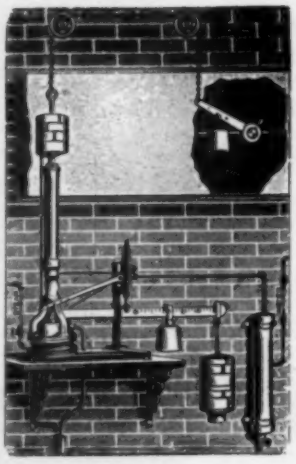
• • *a symbol of worth, value, unalloyed.*

MEANS "GOLD."

• • *the hallmark of ancient goldsmiths' guilds, indicating pure, unquestioned quality.*

LOCKE MEANS
RELIABILITY EFFICIENCY
IN VALVES AND VALVE
REGULATORS*



* The highly sensitive Locke Hydraulic Regulator, on whose scale beam a movement as slight as 2/1000 of an inch will secure operation. Speed of operation obtained and regulated by discharge valve behind water motor.

You may depend on your Locke Regulator for perfect performance. For 75 years the name LOCKE has ranked highest in its own field of critical production and operation; the name indicates utter reliability. A Locke-trained engineer will confer with you on request.

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With the coming of peace and a return to the American way of producing goods at a profit in highly competitive consumer markets you'll *have* to be certain that every step from initial blueprint and tool design, through the machining, stamping and assembly line, up to packaging and delivery is planned and executed with utmost efficiency and with the minimum of cost.

In the production of war munitions Oiljak has maintained an enviable record of production of intricate parts and on time deliveries, in accordance with strict Government inspection—and has actually reduced the estimated and approved cost, thus saving the Government considerable sums, by skillful planning and supervision of the work. These same skills in metal manufacturing, improving designs and reducing costs are available to manufacturers as they convert to peacetime merchandise. It may transmit your penny savings into dollar profits to confer with us on any metal manufacturing problem.

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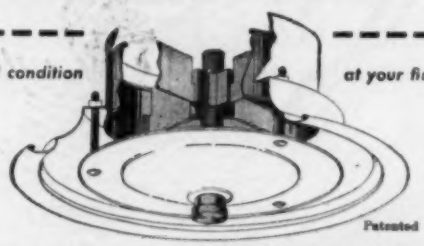
How to control supply-air diffusion

to meet specific job requirements and occupant desires.

Direction and volume of air discharged by every KNO-DRAFT Air diffuser can be adjusted quickly and accurately at any time for system balancing, ceiling heights, seasonal requirements, temperature differentials and the desires of the occupants.

Any desired condition *at your finger tip.*



KNO-DRAFT *Type K Adjustable Air Diffuser with Type D Volume Damper*

By simply turning the air adjustment screws (easily accessible from under the unit), the inner cone may be raised or lowered to secure any angle of air direction required. The built-in volume damper (regulated by the hand-turning knob) varies the air outlet aperture uniformly without affecting the outlet velocity or diffusion pattern.

Free Handbook: *Contains clear sketches, charts, dimension prints and instructive text that simplifies the selection and installation of air diffusers. Write Dept. D4.*

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Air Diffusion *Air Purification* *Air Recovery*

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CONNOR

As amended May 9, CMP regulation 9-A, which controls the materials and parts that a repairman may buy, prohibits the use of the AA-3 rating for (1) refrigeration condensing units, (2) low side units (such as unit coolers); and (3) cabinets or other insulated inclosures, in addition to the prohibition already established for specified types of radio repair parts and for paint.

The amendment is designed to prevent use of the specified refrigeration repair parts for any purpose other than actual repair work, WPB said. These parts may now be obtained by a repairman only by extending a customer's rating or by using a rating assigned through an application on form WPB-1319.

Water Heater Limitation Order Revoked

Revocation of the limitation order (L-185) that controlled production of water heaters was reported May 26 by the WPB. This action is expected to result in a slight increase in the number of heaters available for civilian purchase this year. L-185 restricted the use of copper, stainless steel, and monel metal in the production of all types of water heaters. Production and distribution of water heaters remain subject to other applicable orders and regulations of WPB.

Limitation Order L-123 Is No More

The WPB announced June 2 the revocation of general limitation order L-123, which covered production and distribution of 26 specific items of general industrial equipment, among which were air filters, air washers,

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ATOMIZING SPRAY NOZZLES, SPRAY POND NOZZLES, and CONDENSER WATER DISTRIBUTORS

For Vertical Shell and Tube Ammonia Condensers

ALL MARTOCELLO SPRAY NOZZLES are manufactured with precision and of a design which has been thoroughly tested for maximum results and durability. They are guaranteed to give satisfaction. Successful, efficient results depend largely upon selecting the proper number, type and size of Nozzles suitable for your installation.

THE MARTOCELLO CONDENSER WATER DISTRIBUTORS are now used as standard equipment by Progressive Refrigerating Engineers in solving their Manpower problem, because they require no attention and assure users of the lowest Condenser Operating Pressures and Minimum Power Cost.

It will pay you to consult us. WRITE or WIRE for further information.

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HAYS AIR-FILTER GAGE

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If you are confronted with the problem of not knowing when the collected dirt in your filters is of sufficient density to decrease operating efficiency, install a HAYS Air-Filter Gage. The HAYS indicator shows amount of air resistance at all times—tells when to renew filter element—eliminates guess work—can be made to sound alarm when resistance is excessive. Write for full information. Ask for HAYS Bulletin A-F G.

The HAYS CORPORATION

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Operations are safer with

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Air Conditioning

Hospitals are finding year 'round air conditioning an indispensable aid in operating rooms. Patients, doctors, and staff are all greatly benefited by its controlled temperatures and invigorating freshness.

Years of experience in this work have taught us how best to satisfy the special requirements of operating rooms.

High relative humidity is necessary to carry away static electricity; explosion-proof motors and switches are used; fresh conditioned air is admitted in unusually large proportions: controls are automatic, but can be instantly adjusted by the surgeon. Drafts, noise, dust, and unsteady conditions are avoided.

Does your hospital have air conditioning? Would you like to get literature on the subject? Write to

DEPENDABLE REFRIGERATION SINCE 1882

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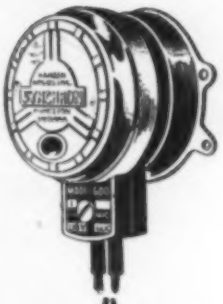
WAYNESBORO, PENNA. U.S.A.

The Detroit Osteopathic Hospital Uses Frick Air Conditioning in this Operating Room

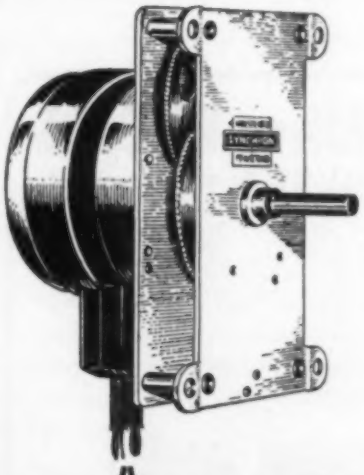
SYNCHRON ★ TIMING MOTORS



— still at war —

but expecting soon to be demobilized

★ For nearly four years the SYNCHRON factory has hummed steadily on war production, building specially designed controls for the Army and Navy. With the reduction of war requirements, however, we will be at liberty to channel our efforts into the production of synchronous timing motors and time machines for your post-war timing devices.



TIME MACHINES

★ The new SYNCHRON Motors and Time Machines will embody many improvements developed in our laboratories during these last few years. Improvements that have been tried, tested, and proven worthy on all the battle fronts of the world. These motors and machines—we confidently expect—will soon be in quantity production for you!

★ *Write for engineering data.*

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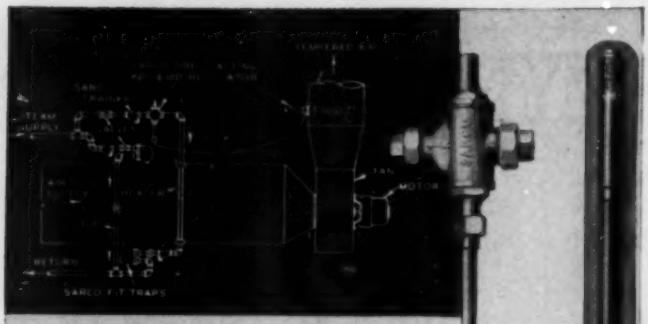

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The Sarco KR-14 temperature regulator is a self-operated, liquid expansion type control, packless and easy to install. Used for air conditioning, refrigeration, dryers, ovens, ducts and all types of industrial process work. Temperatures 0° to 400° F., ½ to 8". Ask for Catalog No. 600.

KR-14

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arc welding machines, compressors, industrial dust collectors, fractional horsepower electric motors, fans, blowers, and exhausters, flexible metallic hose, tubing, and fittings, heat exchangers, high pressure blowers, industrial drying ovens, pressure vessels (including air receivers), pumps, stationary steam engines, insulation blowing machines, and oxyacetylene apparatus.

The production and delivery of these items remain subject to all other applicable orders and regulations of WPB, the agency said.

Sewer Pipe Restrictions Removed

Simplification and standardization restrictions on the manufacture of vitrified clay sewer pipe have been removed through revocation of order L-316, the WPB has announced. Manufacture was limited by the order to the sizes and types of pipe specified.

Restrictions on Steel Boilers Removed

Restrictions on the manufacture of low pressure steel boilers intended for stock were removed last month by the WPB through an amendment to direction 1 to table 14 of the general scheduling order, M-293. The direction formerly prohibited manufacture of high and low pressure steel boilers intended for stock, except on specific WPB authorization. Restrictions on high pressure boilers remain unchanged.

The steel order, M-126, which was revoked May 16, prohibited the manufacture of low pressure steel boilers. Removal of restrictions on these boilers from direction 1 to table 14 of M-293, is in line with permitted manufacture resulting from revocation of the steel order, WPB said.

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is THERMOSWITCH equipped!

Temperature control — maintained by Fenwal THERMOSWITCHES — keeps food piping hot and flavorful in mobile food containers such as that pictured here. If you manufacture a product requiring controlled temperature, investigate Fenwal THERMOSWITCHES!

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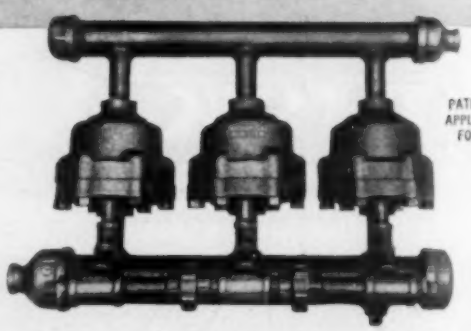
Purify Any Pressures, Air or Gas, with Bird-White Multiple Unit *Pur-O-fier*



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Three Models Available

Model A-1 furnished with a 1 inch turbo-rotor and will accommodate volumes from 1 to 8 cubic feet.

Model A-2 has a 2 inch turbo-rotor and can accommodate volumes from 10 to 35 cubic feet.

Model A-4 has a 4 inch turbo-rotor and can accommodate volumes from 35 to 100 cubic feet.

Bird-White multiple unit Pur-O-fiers save time and money by protecting air-operated machines, gauges and controls from contamination. They give positive purification to air or gas lines regardless of fluctuating pressures or high volumes.

The perfectly balanced Turbo-Rotor purifying action makes them sensitive to both regular and intermittent pressures. Write for Bulletin 10 giving complete details.

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PUMPS YOU CAN TRUST

If you are a user of pumps FOR ANY PURPOSE you will welcome acquaintance with the modern, efficient and lasting "PUMPS by AURORA." Built to highest standards in the belief that EVERY pumping job is IMPORTANT.

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BILGE
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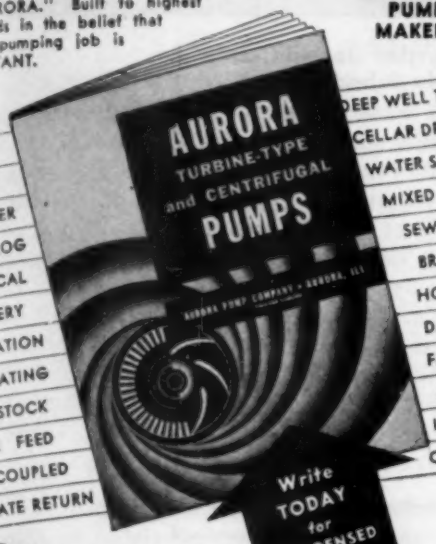

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CELLAR DRAINERS
WATER SYSTEMS
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HOUSE
DAIRY
FARM
AND
MANY
OTHERS

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80 Loucks St., AURORA, ILLINOIS

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FOR HEATING AND COOLING IN A WIDE RANGE OF SIZES

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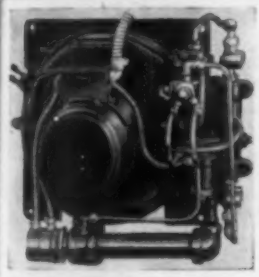
Pioneer Manufacturers of Square Finned Tubing in the United States



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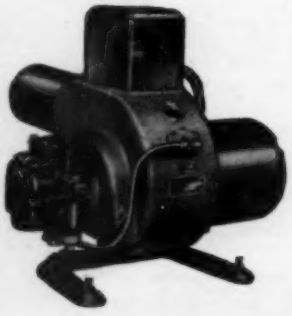
BANKHEAT BURNER
is ideal for conversions and for a wide range of domestic and industrial installations.



IT TAKES MORE THAN FINE PROMISES TO MAKE A DEALERSHIP LAST!

The real test comes in the years that follow the "honeymoon" . . . in the years when you learn how well those easy promises are kept.

It's not just an accident that 75% of the dealerships we have established in the past 42 years are still going strong . . . still mutually profitable . . . still mutually cordial. That fact will tell you that Johnson Burners are what we claim them to be, and that we believe in keeping not only the letter but the *spirit* of our agreements.

It will pay you to remember this if you are considering a complete oil burner "line" that will make money and friends for you. And don't forget that no other burners can offer greater economy and dependability nor more advanced engineering than time-tested Johnson Burners.

If you want a franchise of which to be proud, find out if there's a Johnson dealership open in your territory. We'll gladly tell you.

Johnson Oil Burners

Builders of fine Oil Burner Equipment since 1903

S. T. JOHNSON CO.
940 Arlington Ave., Oakland 8, Calif.
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SPEEDING THE WAR EFFORT of THESE BUSY PLANTS

"American"
COLD PIPE, CONDUIT and TUBE BENDING MACHINES

Bridge-builders, shipyards, engineering firms—busy with war work—depend on these machines! They'll speed peace-time conversion, too. *Twelve types:* hand operated capacities from ¼ to 6" inclusive; motor operated, ½ to 8" inclusive. *More than 12000 customers can testify to the dependability of "American's" 12 types of machines.*

A Few Of Our More Than 12,000 Customers: Bureau of Ships, Wash., D. C.; Henry J. Kaiser Co., Calif.; Pacific Bridge Co.; Bethlehem-Hingham Shipyards; Hercules Powder Co.; Stone & Webster; E. I. Du Pont de Nemours & Co.; Crane Co.

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"American" PIPE BENDING MACHINE Company INC.

Quick Deliveries
51 PEARL ST.
BOSTON, MASS.

MEETINGS & CONVENTIONS

Heat Transfer Session, Talk on Oil Supply Scheduled

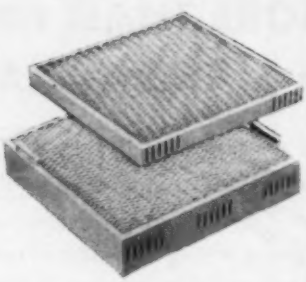
A paper on heat transfer from a cylindric surface to air, by Max Jakob, Illinois Institute of Technology, and W. M. Dow, Armour Research Foundation, is to be presented at 2:30 p.m., June 19, during the two-day conference of the Chicago section of the American Society of Mechanical Engineers at the Stevens Hotel. At a banquet the same evening, Dr. Robert E. Wilson, chairman of the board of the Standard Oil Co. (Ind.) will talk on America's future oil supplies. Other papers to be given during the conference comprise those cancelled from ASME's semi-annual meeting. The chairman of the Chicago section is F. H. Lane, 205 W. Wacker Dr., Chicago 6, Ill.

Stoker Makers Streamline Meeting

Arrangements have been completed to hold the annual meeting of the Stoker Manufacturers' Association at the Stevens hotel, Chicago, August 22. This meeting will be a one day business conference, streamlined to conform with government regulations governing the holding of meetings. Business sessions will be held in the morning and afternoon with a group luncheon and the annual dinner in the evening. In order to comply with government regulations, attendance is restricted to members and associate members of the SMA.

SEEKING PROFITABLE NEW LINES?

Check up on the "BADGER" Heavy Duty Industrial Filter . . . Franchises are Available



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A LARGE and profitable market awaits your introduction of this permanent type "BADGER" Filter—specially designed for extra heavy duty and industrial air cleaning services. Extensive use of this highly efficient "Badger" Filter shows results definitely measured in terms of improved air filtering, greater dust-holding capacity, reduced maintenance costs.

Write for details about our protected distributorships, territories available, and prices and discounts.

Badger CORPORATION
343 East Brown Street
Milwaukee 12, Wisconsin

MY INDUSTRIAL STOKER BUSINESS IS BOOMING!

I'm selling stokers to office buildings, hospitals, schools, churches, hotels and other places that use commercial or industrial sizes. At the same time, I am building up a nice prospective customer list for the smaller domestic models and delivering as fast as they are available.

Get Going now with

GEHL STOKERS

- Engineered to do a better job for more years, by a 78-year-old company.
- Gehl reputation means customer confidence.
- All-cast chassis that resists rust and corrosion.
- Barometric, automatic control of chimney draft, and many other advantages that make selling easier.

WRITE today for literature and dealer plan. Start building your postwar stoker business NOW.

Sizes to meet various requirements

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Established 1867 Dept. BF-830 West Bend, Wisconsin

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PLASTIC FAN BLADES AND BLOWER WHEELS

BETTER FAN satisfaction is assured when you equip your fans with Burden Plastic Blades. These quiet propeller type modern blades have a much lower noise level. They have longer life and weigh only 1/5th to 1/4th as much as metal blades. Yet they have the same structural strength.

Burden Blades have been tested from —60 to 300 F. They are resistant to corrosive action. Low moisture absorption.

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Overlapping — Cloverleaf — Single Blade

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Condensation units for any capacity, from 1,000 to 65,000 sq. feet of radiation, and 1.5 to 97.5 gallons per minute are available in the complete Sterling line. Duplex and underground models are available.

With Pump and Motor equipment best adapted for long, dependable service, Sterling Condensation Pumps meet the industry's highest standards of performance and service.

Consult your local jobber, or write for complete information and prices.

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TONNAGE LABOR and SHIPPING

Hopper or Bin Feed. 200 to 800 lb. per hour. Clinker or Side Dumping Grate.

Built to stand up under the hard usage of industrial installations, the Frederick Stoker is highly regarded and widely used in industry.

Frederick design insures thorough fuel combustion; maximum utilization of heat-giving gases, which results in lower coal consumption. Corresponding conservation of labor is thereby effected, and less coal transported releases shipping for other vital needs.

Frederick engineering features—the fully active grate surface . . . no dead plates . . . continuous speed type transmission and completely enclosed wind boxes and mechanism—are described in our Stoker catalog. Send for it.

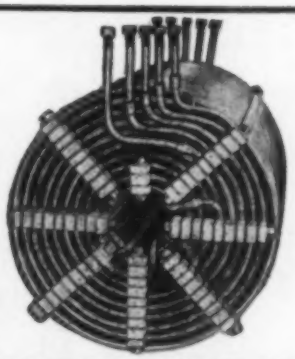
WE ALSO MANUFACTURE fine Centrifugal Pumps especially designed for efficient service in a specific industry. Engineering consultation available without obligation.

THE Frederick IRON & STEEL CO.

Frederick, Maryland

STOKER SPECIALISTS SINCE 1918

INTO THIS COIL ➡ WE BENT



half a mile of COPPER TUBING

Here's a job typical of Swan's skill in precision pipe and tube bending. A certain naval condenser unit takes a lot of copper tubing—two tons of it! *Half a mile of it!* To be bent into a coil no bigger than a small clothes closet. Thermal requirements for maximum efficiency of the unit make necessary the placement of the coil surfaces with great precision in all three dimensions.

Swan Engineering did it!

And in quantity!

And on time!

Use our advisory engineering service in connection with your bending problems. Swan Engineering will quote promptly on bending jobs large or small, simple or complicated, in any of the usual metals or alloys including stainless steel and aluminum. *Send your bending to Swan!*

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Bend Pipe On The Job

Do it *Quicker-Easier* with

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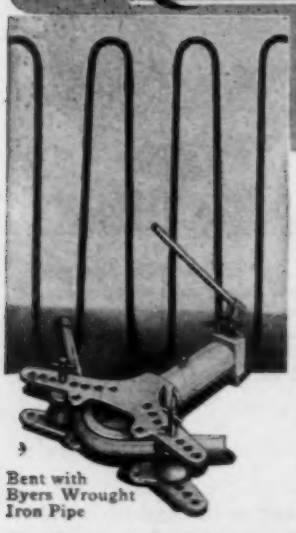

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You start saving valuable working time and reduce material costs the day you use a Tal Prestal Pipe Bender. This efficient, easy to operate, portable machine reduces by 60% the need for fittings or welds. It bends ⅜" to 3" wrought iron or steel pipe up to 180°, cold, in one single, fast operation without moving the pipe, without heating or filling. With a Tal Bender you get a job to be proud of, neat, smooth, workmanlike, free from kinks or wrinkles. Hundreds of leading contractors already know that this best engineered, money making machine repays its low cost over and over every few months. Write for bulletin . . . today!

TAL'S PRESTAL BENDER, INC.
Dept. H.P.-6 Milwaukee 2, Wisconsin

"Products of Tomorrow" Exposition Announced

The first annual "Products of Tomorrow" exposition is being planned for an opening January 18, 1946, subject to wartime exigencies, according to an announcement from Marcus Hinson, general manager of the exposition, which is to be held at the Coliseum, 1513 S. Wabash Ave., Chicago 5, Ill. The exposition is to comprise two main divisions, consumer and industrial products, with the addition of others as the demand requires. Plans contemplate the use of a million square feet to accommodate everyone with a product to introduce.

Patent Office Announces New Service

The United States Patent Office has put in operation a new service to industry and inventors, the purpose of which is to bring to the attention of the nation patented inventions under which the owners are willing to grant licenses on reasonable terms. It is hoped that such information will lead to greater employment opportunities in the reconversion period, as well as permit industry to become acquainted with what is being done in various fields.

A Register of Patents Available for Licensing is now being established, and will be maintained in the Patent Office. Patents recorded on this register will be available to the public for inspection in Washington, D. C. Lists of such patents will be published in the Official Gazette of the Patent Office.

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